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Aircraft Fuels*

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June 28, 1938

I. Introduction

THE subject of aviation fuels has been discussed in recent literature (references 1 to 13 inclusive) from a variety of angles, and it may fairly be said that additional data as to the effects of octane number and fuel type on full-scale engine and aircraft performance are much more needed at the present time than further interpretation of the limited existing data.

The present paper is confined to a discussion of, first, aviation fuel knock-test methods and the octane number scale, particularly with regard to current experimental work in the Ethyl Gasoline Corporation Laboratories on supercharged engines for high octane fuels; and second, the characteristics of high octane fuels (above 83 octane number), particularly with respect to lead response, and the effects of latent heat.†

The advantages of high octane fuels in improving both engine and aircraft performance are today accepted facts. The improvements in engine performance are very definite, particularly with respect to increase of output. Data as to reduction of specific fuel consumption are more meager than those concerning power output. The effects of improved engine performance on aircraft performance with respect to take-off, climb, range, and earning capacity are still somewhat nebulous, and published figures are largely calculated rather than the result of flight test.

From data available, the outstanding effects of octane number increase on engine and aircraft performance may be summarized by the following which represent performance gains when a fuel of 100 Army octane number is substituted for one of 87 A.S.T.M. octane number: a gain of up to 30 percent in take-off power without reduction of specific cruising fuel consumption, a reduction of 15–20 percent in cruising specific fuel consumption without increase of take-off power, and a reduction of 45 percent in length of take-off for very large airplanes (based on 20 percent power increase). When fuel improvement is entirely used up in added take-off output, this is accomplished by increased boost without change of compression ratio. When improvement in specific cruising fuel consumption is desired this is obtained by increase of both air-fuel ratio and cylinder-compression ratio, and the latter, if carried far enough, may actually reduce take-off power. By use of very high compression ratio, specific cruising fuel consumptions of less than 0.4 lb. per b.h.p.-hr. on 100 octane fuel have been obtained in extended endurance running. In practice, in many cases, an increase of octane number is likely to be used partly for improvement in take-off output and partly for reduction of cruising fuel consumption.

* Opinions expressed and interpretations of data are solely those of the authors and should not be considered as reflecting the views of the laboratories with which the authors are associated. In many cases the opinions expressed are the authors' interpretations of data submitted to the C.F.R. and should not be considered as in any way expressing the findings of the C.F.R.

† F. Gillig is responsible for all of the supercharged knock-testing data embodied in this paper and for the preparation of illustrations.

However, while knowledge of the full-scale engine "knocking"* behavior of fuels of 80 octane number and below is now fairly complete and quite adequate for general service use, information concerning the full-scale behavior of fuels of 83 to 100 or higher octane number is far from complete, and in particular is quite inadequate if fuels and antiknock compounds of all available chemical types are considered.[4,12]

Edgar[14] has recently emphasized the fact that the service behavior of aviation fuels is only reasonably constant for a given octane number because the materials permitted in the fuels are restricted to a very narrow range of chemical composition. On the North American continent there are in general only three components permitted in aviation fuels, namely, straight-run gasoline, isoparaffins such as isooctane and isopentane (2,2,4-, 2,2,3-, 2,3,4-trimethylpentane, etc., and 2-methylbutane), and tetraethyllead. If cracked gasolines, branched-chain olefins, aromatics, alcohols, ethers, and ketones, with or without tetraethyllead or aniline additions, were all permitted components of aviation fuels of 83 octane number or more, the situation with respect to full-scale engine knocking behavior would probably become chaotic.

In discussion of the relative full-scale engine knocking behavior of diverse fuels, one of the authors in 1930 stated that "the question of antiknock values of widely different fuels in both aircraft and fuel-test engines is one concerning which but little is known, nor is a thorough understanding likely to be gained for the next two or three years."[15] This statement appears to have erred on the side of optimism, although by limitation of fuel type, as above described, an adequate control of effective antiknock value has been achieved on the North American continent.

II. Relationship of Full-Scale Engine and Knock-Test Engine Behavior

1. Full-Scale Engine Investigation of Fuel Behavior

During the World War it was found that the performance of aircraft engines was subject to considerable change when using gasolines made from crudes of widely varying type. Investigation by A. H. Gibson in 1917–18[16] at the Royal Aircraft Establishment (England) showed that air-cooled engines were particularly affected by the relative knocking tendency of the fuel. Gibson's investigations included tests of a highly cracked gasoline in both air-cooled and water-cooled cylinders. This gasoline was much better than the current supply of straight-run gasoline in a water-cooled cylinder but only equal to or worse than the straight-run fuel in air-cooled cylinders. As far as the authors know this was the first positive observation of a problem which in recent years has been the cause of a large amount of investigation and which is still not solved (and is unlikely of complete solution). The classical investigations of Midgely and Boyd and of Ricardo firmly established the relation of engine performance to fuel knocking characteristics.

The aircraft engine, however, still continued to be supplied with fuel of widely varying knock characteristics despite attempts at control by means of chemical specifications. In England a fair measure of satisfactory control was established, although this was due more to the use of highly aromatic Asiatic crudes than to effectiveness of the specifications. In 1929, in the United States, aviation gasoline was generally considerably inferior in knocking characteristics to the majority of the automobile fuels then on the market. Increasing use of air-cooled engines, in particular those of more than 5-in. cylinder bore, finally made it obvious that chemical specifications were entirely inadequate and that some measure of effective control must be quickly established. Normal heptane and isooctane had already been established by Edgar[17] as tentative reference fuel standards for expressing knocking characteristics. Early investigation of current fuels indicated that octane numbers were commonly below 50 for straight-run Mid-Continent gasolines and that most California straight-run gasolines exceeded 70 octane number. These California fuels were generally known to obviate the overheating troubles usually occurring in air-cooled engines with "run of mine" Mid-Continent fuels. In 1929, it became obvious that expression of knock characteristics in terms of some engine function, such as the compression ratio necessary to produce knocking in a given engine, was unsatisfactory. The octane scale was adopted, and sealed the fate of advertising claims such as "highest antiknock value" and of many gasolines thus described.

In 1929, however, it was still generally thought that two fuels of equal "knock rating" or octane number in one engine should be equal in all other engines. This equality was not always found in practice and the lack of it was usually charged to experimental error. With the introduction of high-temperature liquid cooling with ethylene glycol, systematic and controlled variation of cylinder temperature became possible. Octane number determinations of diverse fuels, at widely varying cylinder temperatures in laboratory knock-test engines, at once indicated that relative knocking behavior was a function of engine conditions and that the variations found were beyond experimental error.

Tests of diverse fuels in full-scale engines indicated that the conditions then used in laboratory knock-test engines did not satisfactorily predict the relative value of fuels in aircraft engine service. Laboratory knock tests at that time were usually conducted at 600 r.p.m., 212°F. jacket temperature, and without mixture heating devices. It was found that increase of cylinder or

* "Knocking" is here used to describe any form of uncontrolled combustion whether or not manifested by audible knock.

mixture temperature in conjunction with a higher rate of engine revolution was essential for even a partially satisfactory prediction of full-scale knocking behavior. By 1932, it was generally realized that the above findings made the problem of satisfactory specification of aviation fuels a complicated and difficult process if a wide range of components was to be allowed.

In the United States the U. S. Army Air Corps carried out a considerable amount of work comparing full-scale engine and knock-test engine performance of diverse fuels, and published data on this work in 1930.[15,18] In 1930, the Air Corps started the use of 87 octane number fuel, this being the first aviation fuel specification embodying an octane number requirement.

In 1933, it was generally agreed that the problem of investigation and specification of aviation fuels was one which could best be attacked by cooperative effort. The Cooperative Fuel Research Committee (C.F.R.) accepted sponsorship of this investigation. Representatives of engine manufacturers, the military and other government services, and fuel producers, laid out a program to determine the relation of full-scale engine and knock-test engine behavior of a series of diverse fuels of 70 to 90 octane number and this work was completed in 1935 and published[4] in 1936. Subsequent to the completion of the first program, the Canadian National Research Council became a cooperating member of the C.F.R. and has recently completed and reported full-scale tests on all the fuels previously used in the United States for the first program. A further program was then undertaken on fuels of 87 to 100 octane number and this has been partially completed and an interim report recently rendered.[12]

For the second C.F.R. program it was decided that the knock-testing procedure in which any fuel tested is compared with an isooctane-heptane blend should be followed as closely as possible in the full-scale engines. The first program used reference fuels consisting of straight-run gasoline with or without lead additions, but this was thought to be unsatisfactory and it was agreed that the full-scale reference fuels should be as close as possible to isooctane and *n*-heptane. Large supplies of a high purity technical isooctane known as C.F.R. S-1 reference fuel[19] were segregated. A straight-run gasoline of slightly below 20 octane number known as C.F.R. M-1 reference fuel[20] was also segregated as the best substitute for normal heptane which was not available in the required quantities. For octane numbers up to 100, blends of S-1 and M-1 are used, and S-1 plus lead for values in excess of 100 octane number. The procedure used involves comparing each fuel tested with C.F.R. reference fuel blends having slightly lower and slightly higher full-scale antiknock values than the fuel being tested. The use of the C.F.R. S-1 and M-1 reference fuels has led to a much better understanding of full-scale engine octane numbers.[4,12]

The first and second programs have both had the primary purpose of determining the relation of fuel knocking characteristics in full-scale engines and knock-test engines. The relations found in the first and second programs are summarized below, following the description of current standard knock-test methods.

2. *Standard Knock-Test Methods**

Several knock-test methods have been standardized and these considerably affect the octane numbers of fuels which are subject to wide variation in this respect as engine conditions are varied. The best known of these test methods are the A.S.T.M.,[21] the C.F.R. Research,[22] the British Air Ministry,[23] and the U. S. Army Air Corps.[24] The most important test conditions and their effects on typical fuels for these four methods, all using the C.F.R. engine, are as follows:

(a) A.S.T.M. Method. The test conditions are: 900 r.p.m.; 212°F. jacket temperature; 300°F. mixture temperature; knock equated by bouncing pin. This method is fairly severe on cracked gasolines and aromatic blends. At high octane numbers it gives moderate lead response at low lead concentrations and slight response at normal and high concentrations. It is more generally used for testing aviation fuels than any other method.

(b) C.F.R. Research Method. The test conditions are: 600 r.p.m.; 212°F. jacket temperature; no mixture heating; knock equated by bouncing pin. This method gives much higher octane numbers than the A.S.T.M. to cracked gasolines and aromatic blends. It rates benzol at a great deal in excess of 100 octane number. Little information is available as to its effects on normal straight-run aviation gasolines and their blends with lead.

(c) British Air Ministry Method. This method is identical with the A.S.T.M. except for the use of 260°F. mixture temperature. It gives somewhat higher octane numbers than the A.S.T.M. method to benzol blends and cracked gasolines. In the case of leaded straight-run gasolines of about 87 octane number, the A.S.T.M. octane numbers are sometimes higher and sometimes lower than those obtained with the British Air Ministry method.

(d) U. S. Army Air Corps Method. The test conditions are: 1200 r.p.m.; special small bore C.F.R. cylinder; 330°F. jacket temperature; no control of mixture temperature; "knock" equated by thermal plug. This method gives ratings which are almost identical with those given by the A.S.T.M. method for cracked gasolines, clear straight-run gasolines, leaded straight-run and cracked gasolines, and straight-run gasoline-benzol blends of 80 octane number or less. C.P. benzene is rated 88 octane number (by definition)

* The units used in this paper are those common in the United States. Thus, lead concentrations are all in cubic centimeters of $PbEt_4$ per U. S. gallon. Temperatures are all in Fahrenheit which is standard in the petroleum industry.

by this method. While leaded fuels of about 80 A.S.T.M. octane number have almost identical Army octane numbers, divergence between the values given by the two methods begins at about 80 octane number and the Army octane numbers become progressively higher with increase of octane number in the case of fuels containing 2 to 3 cu. cm. of lead. Thus, a leaded straight-run fuel with $2^1/_2$ to 3 cu. cm. of lead and of 87 A.S.T.M. octane number will usually be rated 90 to 92 octane number by the Army method.

3. *Summary of Conclusions on Full-Scale Test Results and Their Relation to Current Knock-Test Methods.*

The first and second C.F.R. programs have shown the following:

(a) Diverse fuels, of 70 to 83 A.S.T.M. octane number, consisting of: clear and leaded straight-run gasolines of widely different type, clear and leaded fuels of cracked or unsaturated types, and unleaded benzol-straight-run gasoline blends, all have their full-scale engine behavior satisfactorily predicted by the A.S.T.M. method.

(b) Blends of straight-run gasoline with $2^1/_2$ to 3 cu. cm. of lead, having 87 A.S.T.M. and 90 to 92 Army octane numbers, are matched in full-scale performance by a 94 to 96 A.S.T.M. octane number blend of C.F.R. S-1 and M-1 reference fuels. Thus the lead blends are under-rated 6 to 8 octane numbers by the A.S.T.M. method and 2 to 6 octane numbers by the Army method.

(c) Blends of straight-run gasoline and isooctane with 3 cu. cm. of lead, having 98 to 99 A.S.T.M. and 100 Army octane numbers, are matched in full-scale performance by S-1 blended with $^1/_2$ cu.cm. of lead. Discussion below indicates that S-1 plus $^1/_2$ cu.cm. of lead may be taken as equal to $102^1/_2$ octane number. Thus these blends are under-rated about 4 octane numbers by the A.S.T.M. method and about $2^1/_2$ octane numbers by the Army method (cf. below for discussion of relative size of octane numbers).

(d) The behavior of 87 A.S.T.M. octane number benzol blends (85 Army octane number) varies widely depending on full-scale engine type and operating conditions. In some full-scale engines the A.S.T.M. method under-rates these blends 8 octane numbers, and the Army method under-rates them about 10 octane numbers. In other engines the A.S.T.M. method slightly over-rates them and the Army method gives substantially correct ratings.

The above conclusions concerning over-rating and under-rating, etc., all refer as far as possible to the relative full-scale behavior of the fuels discussed in comparison with S-1 and M-1 reference fuel blends. If perfect correlation between full-scale engines and the knock-test engine could be obtained, any test fuel equaling a given blend of S-1 and M-1 in the knock-test engine would also be equal to the same blend in all full-scale engines.

It is the authors' opinion that none of the current standard knock-test methods are entirely satisfactory for the following reasons:

(e) None of the methods have sufficient sensitivity to change of octane number at the 100 octane level or above it. Thus, the addition of 1 cu. cm. of lead to isooctane does not produce a large and definite change in engine performance. This feature has not been of much significance in the past but it is now a matter of considerable importance.

(f) The A.S.T.M. method is deficient in evaluating high octane number lead blends. It is obvious from the full-scale data discussed above that straight-run gasoline-lead blends and straight-run gasoline-isooctane-lead blends must have their A.S.T.M. octane numbers qualified in accordance with their lead contents. The Wright Aeronautical Corporation has specified maximum and minimum lead concentrations with this test method as a temporary expedient for control of full-scale octane numbers.

(g) The Army method under-rates high octane number lead blends although to a lesser extent than the A.S.T.M. method. This method also appears to under-rate clear aromatic blends. This method is fundamentally somewhat more versatile than the A.S.T.M., C.F.R. Research, or British Air Ministry methods, since it does not attempt to obtain knock from non-knocking (pre-igniting) fuels such as aromatics and alcohols. The Army method is somewhat objectionable in respect to engine maintenance, this largely as a result of frequent piston ring sticking.

4. *Supercharged Methods*

In view of the insensitivity of existing methods to change of octane number at the 100 octane level, a C.F.R. Committee is studying methods having increased response to change of octane number. The Laboratories of the Ethyl Gasoline Corporation are participating in the work of the committee and have concentrated on studies of supercharging.[25] The supercharging methods which have been worked out are only in the experimental stage, but they do enable the effects of widely different engine conditions upon octane number to be studied and fuels with octane numbers greatly in excess of 100 can at least be evaluated in terms of the power permissible with pure isooctane.

The methods at present used involve operating at (a) 900 r.p.m., 212°F. jacket temperature, and (b) 1800 r.p.m., 385 to 400°F. jacket temperature. The intake pressure is raised with each fuel until light knocking, pre-ignition, after-firing, or back-firing is experienced. With these methods fuels are evaluated on the basis of the indicated power at which any one of above phenomena (knock, etc.) is first experienced.

Owing to the ability of these methods to evaluate

fuels of well over 100 octane number it is not necessary to dilute fuels such as benzol, alcohol, and isooctane when determining either their lead response or the change of octane number due to more or less severe engine conditions (increase or decrease of speed, cylinder temperature, and intake temperature). While the methods are still in the experimental stage, they have proved very useful laboratory tools in studying the relative behavior of new aviation fuels, in terms of older types of known full-scale engine behavior. With these methods both indicated power output (brake plus friction output) and the reference fuel, isooctane plus lead up to 6 cc., are at present used for evaluating fuels of above 100 octane number. At 900 r.p.m. benzene, toluene, methanol, and diisobutylene are all either equal or superior to isooctane plus 6 cu. cm. of $PbEt_4$ (approximately 150 percent of power available on isooctane alone). At 1800 and 385 to 400°F. jacket temperature the antiknock values of these fuels vary between approximately 90 octane number and 100 plus 1.0 cu. cm. of lead.

5. *Summary of Conclusions Concerning Supercharged Knock Testing and Relation to Full-Scale Behavior*

It is the authors' opinion that in knock testing aviation fuels of above 100 octane number, the use of supercharging will eventually prove essential. Supercharging at present involves complicated and expensive apparatus and testing is much slower than with the methods now in use. Furthermore, in the light of present knowledge, supercharging would inevitably appear to necessitate a much more highly trained and more skillful operating personnel than required by the A.S.T.M. or Army methods. However, supercharged fuel testing with a C.F.R. engine is vastly cheaper, simpler, and faster than similar work with a single aircraft engine cylinder. Aviation fuels are used in complex and expensive engines and it is not unreasonable to assume that testing such fuels in the laboratory will involve more expensive equipment than required for automobile gasolines.

Full-scale and laboratory engine knock testing of aviation fuels has been considerably retarded by the generally accepted fetish that audible knock is the major criterion of fuel failure. In the case of automobile fuels audible knock is without question the yardstick by which the public judges fuel performance and thus they should be rated by knocking tendency. In the case of automobiles, either pre-ignition, or a tendency to produce cylinder overheating in the absence of audible knock, is very rarely of significance. In the case of the aircraft engine audible effects produced by combustion only have significance if they are indications of actual or potential engine damage. Aromatics, alcohols, and some completely olefinic fuels, when used in high-output engines with high cylinder wall temperatures, do not produce audible knock but rather go directly into pre-ignition. Pre-ignition in high output engines usually produces extremely destructive cylinder effects in a very short period. Pre-ignition in an aircraft engine often produces cylinder failure within 30 secs. of its onset. Pre-igniting type fuels, when used in aircraft engines at just below the pre-ignition level, may produce serious cylinder and piston overheating, while a knocking type fuel at the same output may produce audible knock with much less liability to engine damage.

In supercharged knock testing with high engine speed and high cylinder temperature, the first manifestation of fuel failure at very high antiknock values (such as isooctane plus 3 cu. cm. of lead or more) is quite generally either after-firing (continued firing on cutting the ignition switch) or pre-ignition. The supercharged test methods used in the Laboratories of the Ethyl Gasoline Corporation evaluate fuel failure by light audible knock, after-firing, pre-ignition, or back-firing. Back-firing is rarely obtained and usually results from the combination of a pre-igniting fuel and a fairly hot spark plug. When back-firing occurs, however, it is very definite and can usually be repeatedly produced or eliminated by increasing or reducing the mean effective pressure by 5 lbs. per sq. in.

Supercharged methods have not yet been developed which give entirely satisfactory correlation with available full-scale data. Present experience, however, indicates that high cylinder wall temperature is necessary if the lead response of full-scale engines is to be duplicated. Aromatics require both high cylinder wall temperature and high engine speed if their ratings are to be close to those given by full-scale engines. Jacket outlet temperatures of 400°F. and more are being used without serious lubrication or maintenance difficulties. High cylinder base temperatures obtained by high jacket inlet temperatures (350°F. or more) appear to be of importance in testing aromatic fuels and high inlet temperatures can be very troublesome with respect to cylinder lubrication and ring wear. Piston and piston ring troubles at 300 lbs. per sq. in. i.m.e.p. and 350°F. jacket inlet temperature have been largely eliminated by piston design, lubrication system modifications, and the use of available strictly commercial lubricants. The supercharged engine in the Ethyl Gasoline Corporation Laboratories requires rather less cylinder maintenance than engines operated in accordance with the A.S.T.M. and Army methods in the same Laboratories.

III. Fuel Combustion Properties

Current information concerning the combustion properties of present and potential aircraft fuels of 83 octane number or more is summarized below. This summary is based on available data from full-scale tests, present standard knock-test methods and experimental supercharged knock-test methods. Considerable emphasis is given to the matter of lead re-

TABLE 1 PHYSICAL PROPERTIES

Fuel Type	Boiling Point °F. at 760 Mm.	Reid(i) Vapor Press. at 100°F.	Freezing Point °F.	Specific Gravity at 60°F.	Gross Heating Value B.t.u. per U. S. gal. at 60°F. Lb.		Latent Heat of Evap. B.t.u. per Lb.	20000 B.t.u. of gross heat. value(iii)	Water Tolerance Sol. of water in fuel % wt.	Sol. of fuel in water % wt.
(1) Gasolines										
(a) Straight-run	..	7(i)	below −76	.69–.76 (ii)	20000–20600	115000–130000	140–150	135–150	0.005(68°F.)	about 0.0006 (68°F.)
(b) Cracked (pyrolytic)	..	7(i)	below −76	.70–.74	about 20000	117000–123000	140–150	140–150	low	low
(c) Synthetic (hydrogenated or catalytically cracked)	..	7(i)	below −76	.70–.72	20000–20600	117000–124000	140–150	135–150	low	low
(2) Branched-chain paraffins										
(d) 2,2,4-trimethylpentane (certified)	211	2.2	−162	.696	20500	119000	140	137	low	low
(e) Commercial mixed isooctanes	206–245	1.3—2.5	..	.70–.72	20500	120000–123000	about 140	about 137	low	low
(f) Isopentane (2-methylbutane)	82	20.4	−256	.625	20800	108000	160	154	low	low
(g) 2,2-Dimethylbutane	122	9.5	−145	.654	20700	113000	about 150	about 145	low	low
(h) 2,2,3-Trimethylbutane	178	3.3	−13	.694	20600	119000	about 140	about 135	low	low
(j) Isododecanes (hydrogenated triisobutylenes) (iv)	330–400	about 0.1	below 0	.75–.76	20400	128000	..	..	low	low
(3) Aromatics										
(k) Benzene	175	3.2	42	.884	18000	133000	170	189	0.062(68°F.)	..
(l) Toluene	231	1.3	−139	.871	18300	133000	160	175	0.046(68°F.)	..
(m) Xylenes	281–289	0.4	−53 to +56	.884–.865	18500	135000	150	162	..	..
(n) Synthetic aromatics with varied side chains on ring	..	low	..	.86–.89	..	..	about 140	..	..	..
(4) Olefins										
(o) Diisobutylenes mixed (branched-chain)	217	about 1.5	−150	.715	20300	121000	140	138	..	..
(p) Mixed	..	..	..	..	..	..	..	..	..	..
(5) Ethers										
(q) Diisopropyl	154	5.3	−125	.729	16900	99000	123	153	.025(77°F.) (30)	.65(77°F.) (30)
(r) tert-butylethyl	155	..	low	.74	16900	104000	..	..	..	..
(s) various branched-chain ethers[29]	..	..	..	..	..	..	..	..	..	..
(6) Alcohols										
(t) Methanol	148	5.3	−144	.797	9500	63000	473	1075	comp. miscible	comp. miscible
(u) Ethanol	173	2.8	−179	.792	12700	84000	368	606	comp. miscible	comp. miscible
(v) Isopropanol	180	..	−129	.791	14400	95000	287	422	comp. miscible	comp. miscible
(7) Ketones										
(w) Acetone	133	7.6	−138	.796	13100	87000	223	354	comp. miscible	comp. miscible
(x) Methylethyl	175	3.2	−124	.810	14500	98000	..	..	probably very high	considerably sol. not comp. miscible
(y) Higher ketones—some of low water solubility	above 200	..	low	about .80	much lower than gasoline		..	..	..	..
(8) Naphthenes										
(z) Cyclohexane	178	..	44	.781	20100	131000	about 160	about 160	..	..

(i) Average maximum Reid vapor pressure when used without blending agent additions. When blending agents are used final blend is usually adjusted to 7-lb. vapor pressure. Where Reid data are not available true vapor pressures are given for pure compounds. True vapor pressure for pure compounds should be almost identical with the Reid figure.

(ii) .76 specific gravity represents highly aromatic type of medium lead response. Such fuels largely used in Europe but use here very limited.

(iii) Comparative measure of mixture cooling effects in comparison with normal gasoline.

(iv) Possible high altitude or safety fuel.

TABLE 2
ANTIKNOCK PROPERTIES

	Fuel Type	Octane Number Clear (vii)						Lead Response (v)					
						Supercharged						Supercharged	
		A.S.T.M.	C.F.R. Res.	B.A.M.	Army	900 r.p.m. 212° F.	1800 r.p.m. 350–400° F.	A.S.T.M.	C.F.R. Res.	B.A.M.	Army	900 r.p.m. 212° F.	1800 r.p.m. 350–400° F.
(1)	**Gasolines**												
(a)	Straight-run	77 max.	.....	78 max.	77 max.	About 75 max.	About 77 max.	H-M	H-M	H-M	H-M	H (vi)	H (vi)
(b)	Cracked (pyrolytic)	65–80	90+ max.	.....	65–80	.....	.....	S-M	S-M	S-M	S-M	..	..
(c)	Synthetic (hydrogenated or catalytically cracked)	76–79	About 79 max.	About 79 max.	75–78	About 75 max.	About 77 max.	H	H	H	H	H	H
(2)	**Branch-chained paraffins**												
(d)	2,2,4-Trimethylpentane (certified)	100	100	100	100	100	100	H	H	H	H	H	H
(e)	Commercial mixed isooctanes	95–99	.....	.....	95–99	.....	.....	H	H	H	H	..	..
(f)	Isopentane (2-methylbutane)	About 90	.....	.....	.....	.....	.....	H (B)	..	..	H (B)	..	..
(g)	2,2-Dimethylbutane	95	.....	.....	.....	.....	.....	..	..	..	..	..	..
(h)	2,2,3-Trimethylbutane	100 + 1.0 cc. approx.	.....	.....	100 + 1.0 cc. approx.	.....	.....	..	..	..	..	..	..
(j)	Isododecanes (hydrogenated triisobutylenes) (iv)	.....	.....	.....	About 95	.....	.....			Probably high			
(3)	**Aromatics**												
(k)	Benzene	100 + 0.6 cc. approx.	Much over 100	.....	88	Over 100 + 6.0 cc.	100 + 0.5 cc. to 95	S-M (B)	..	..	Z S-M (B)	..	Z
(l)	Toluene	100 + 2.0 cc. approx.	Much over 100	.....	98	Over 100 + 6.0 cc.	100 + 5.0 cc. to 99	S-M (B)	..	..	S-M (B)	..	Z
(m)	Xylenes	100 + 2.0 cc. approx.	.....	.....	99	.....	.....	..	..	..	..	..	..
(n)	Synthetic aromatics with varied side chains on ring	.....	.....	.....	About 95	.....	.....	..	..	..	S-M	..	..
(4)	**Olefins**												
(o)	Diisobutylenes, mixed (branched-chain)	84	Over 100	.....	84	Over 100 + 6.0 cc.	About 90	S-M	..	..	S-M	..	S-M
(p)	Mixed	About 80 max.	.....	.....	About 80 max.	.....	.....	..	..	..	S-Z	..	..
(5)	**Ethers**												
(q)	Diisopropyl	.....	.....	.....	98–99	97	100 + 0.2 cc.	H (B)	..	..	M H (B)	..	M
(r)	Tert-butylethyl	.....	.....	.....	100 + 0.1 cc.	.....	.....	..	..	..	S	..	..
(s)	Various branched-chain ethers[29]	.....	.....	.....	.....	.....	.....	H-M (B)	..	..	..	..	..
(6)	**Alcohols**												
(t)	Methanol	98	.....	.....	87–90	Over 100 + 6.0 cc.	90–95	S-Z	..	..	S-N	..	St. N.
(u)	Ethanol	99	.....	.....	.....	.....	.....	S-Z (B)	..	..	S-Z (B)	..	..
(v)	Isopropanol	.....	.....	.....	About 100	About 100 + 5.0 cc.	.....	..	..	..	..	Z	..
(7)	**Ketones**												
(w)	Acetone	100	.....	.....	100	Over 100 + 6.0 cc.	.....	H (B)	..	..	H (B)	S	..
(x)	Methylethyl	100	.....	.....	99	.....	.....	M (B)	..	..	H (B)	..	..
(y)	Mixed radical ketones—some of low water solubility	.....	.....	.....	.....	.....	.....	..	..	..	..	..	..
(8)	**Naphthenes**												
(z)	Cyclohexane	75	85	.....	.....	.....	.....	S-M	..	..	..	..	..

(iv) Possible high altitude or safety fuel.
(v) Lead response compared in general either to: straight-run gasolines, straight-run gasolines plus isooctane or *n*-heptane-isooctane blends.
(vi) Non-aromatic types.
(vii) Values such as 100 + 1.0 cc. indicate cu.cm. $PbEt_4$ per U. S. gallon in certified isooctane.

sponse. The physical properties and characteristic knock-test engine behavior of the most important materials in actual use or which have been investigated for aviation fuels are given in Tables 1 and 2. The data, accumulated from a wide variety of sources (references (26) to (35), inclusive), have not been critically surveyed for high accuracy, but should have sufficient accuracy for discussion of high octane fuel blends.

1. *Heat of Combustion*

In considering values for heat of combustion the following points may be emphasized:

(a) Heat value per lb. is the significant value with regard to the engine itself. Heat value per gallon has, however, some significance since the weight of tankage to carry a gallon of fuel is considerable. Thus, the total weight of fuel and tankage could be the same for a given total heating value in the cases of two fuels, one of which has a high heating value and low density and the other has a lower heating value and a higher density.

(b) Gross heating values are given in Table 1 and are suitable for comparative purposes, although it is probable that the significant value is the lower heating value plus the latent heat of evaporation.

(c) Heat of combustion values can, in practice, only be compared for fuels of equal full-scale octane number. A considerable deficiency in heating value may easily be offset by increase of full-scale octane number (cf. Mixture Strength, below). But since the maximum full-scale octane numbers usually can be obtained without sacrifice of heating value, it is obviously desirable to employ fuels of highest heating value for minimum specific consumption.

(d) Gross heating values depend on the structure and composition of the fuel molecule. Thus, the paraffins have the highest values, which decrease with increase of molecular weight. Olefins are about $1^1/_2$ percent lower than paraffins with the same number of carbon atoms, and naphthenes $1^1/_2$ percent lower than the corresponding olefins. Aromatics are significantly lower than the paraffins, but this may be partly offset in practice by the higher density of the aromatics. Oxygenated compounds may vary from less than 50 percent of the value for gasoline up to a value about equal to benzene.

2. *Allowable Mixture Strength*

(a) In flight operation of an aircraft engine there are two important phases: take-off, and cruising. At take-off, maximum output in conjunction with minimum heat rejection to the cylinder walls is all-important and fuel consumption of no consequence. In cruising, power output is sometimes as low as half that at take-off and specific fuel consumption is often the important factor. Cruising operation usually represents a large proportion of the time involved in any given non-stop flight and specific fuel consumption thus may considerably affect the pay-load carried. The conditions of mixture strength in these two phases of operation are widely different and are influenced by several factors which are discussed below.

(b) In either phase of full-scale engine operation, the allowable air-fuel ratio which may be used with a fuel of any given heating value is a function of the octane number. For example, in the case of a gasoline blended with lead to produce a variety of blends with increasing octane numbers, it will be found that with a rich mixture (low air-fuel ratio), two blends of different octane number will give equal output, cylinder temperature, and general performance. However, on reducing the mixture strength, the lower octane number fuel will produce knocking, overheating, and a drop-off in power, while the higher octane number fuel actually gives more power than it did with the rich mixture.

(c) In obtaining minimum specific cruising fuel consumption in practice, increase of air-fuel ratio has proved to be much more important than the cylinder compression ratio. Outside the aircraft field, cylinder compression ratio is generally regarded as the criterion of specific fuel consumption, and the relation of air-fuel ratio to octane number and specific fuel consumption is not widely known. Increase of cylinder compression ratio may actually increase fuel consumption if the fuel is only suitable for a lower compression ratio, for when the compression ratio is thus increased, the air-fuel ratio must be decreased to avoid knocking. It is the authors' belief that minimum consumption with any given fuel will be attained at the highest compression ratio which allows operation without knock and with the air-fuel ratio giving theoretically complete combustion.

(d) In **(b)** above it has been shown that octane number and allowable air-fuel ratio are related functions for a fuel of fixed heating value. A deficiency in octane number may require operation at a rich mixture, which is in effect a reduction in heating value. Conversely, it is to be expected that a decrease in heating value may be offset by increase in octane number. Buc and Aldrin[26] give data for the relative specific fuel consumptions obtained in dynamometer tests of a 92 Army octane number straight-run gasoline and a 100 Army octane number straight-run gasoline-diisopropyl ether blend. The heating value of the ether blend was only about 93 percent of that of 92 octane number gasoline, but the ether blend gave a 13 percent lower specific consumption. Comparison of the ether blend with a 100 Army octane number isooctane-straight-run gasoline blend showed the isooctane blend to give about 7 percent lower consumption than the ether blend.

(e) In practice, the use of rich mixtures at take-off to compensate for a deficiency in octane number is carried to the point of diminishing returns. Air-fuel ratios of about 10 to 1 giving specific consumptions of about 0.75 lb. per b.h.p.-hr. are general. However, with present hydrocarbon fuels, a 10 to 1 air-fuel ratio is much lower than the maximum power air-fuel ratio, and as a result

gives about 10 percent less power than could be obtained from a fuel of high enough octane number to allow operation at maximum power mixture strength. Air-fuel ratios of even less than about 10 to 1 would be used for take-off, were it not for the fact that, although the richer mixture allows more boost to be used, the added boost does not result in increase of power output.

At the take-off condition it is desirable that the maximum power mixture strength should be much richer than the maximum knock mixture strength (*i.e.*, that producing maximum cylinder temperature) and this is the case for many fuels. If the mixture be made still richer than that for maximum power, the tendency to knock is still further reduced. These reductions in knocking tendency are partly the result of cylinder wall and flame temperatures being lowered as mixture strength is increased.

Fuels of different chemical types apparently vary considerably in the relation of maximum knock and maximum power mixture strength, and also with respect to the rate at which power falls off as the mixture is made richer than maximum power. For example, alcohols do not drop off in power at mixture strengths in excess of maximum as rapidly as do hydrocarbons[36] and aromatics in general are superior to straight-run gasolines with respect to power drop at very rich mixtures.

Excessively rich mixtures at take-off are used both to diminish cylinder temperature and to add to air consumption by mixture cooling. In some full-scale comparisons of 87 A.S.T.M. octane number benzol blends with straight-run gasolines of the same full-scale engine octane number, it was found that while the benzol blends did not lose as much power at very rich mixture as did the gasolines, the gasolines produced a more rapid drop in cylinder temperature. In this particular set of comparisons the loss in power for a given degree of cylinder temperature reduction was about equal for the straight-run gasolines and the benzol blend. This finding may have been peculiar to the particular engine type but does indicate that engine cooling produced by rich mixtures at take-off is a function of the fuel type.

(f) There is evidence that fuels of widely different types, which may be equal in full-scale octane number at cruising conditions with high air-fuel ratios, may not be equal under take-off conditions at low air-fuel ratios and *vice versa*. Data showing that diisopropyl ether blends are equally as good as isooctane blends of the same octane number at take-off, although definitely inferior under cruising conditions, have been given by Buc and Aldrin.[26] Current full-scale testing methods in the United States involve comparisons of fuels at both cruising and take-off conditions.[4,12] Data as to the relative behavior of the various fuel types under the two sets of conditions are limited. To date, in the United States at least, the abnormally low specific cruising fuel consumptions which are now desired for some types of operation, have all been obtained with blends of non-aromatic straight-run gasolines with commercial isooctane. It is possible that such low consumptions (0.4 lb. per b.h.p.-hr. and lower) are only possible with paraffinic fuels. Data showing equally low consumptions for aromatic fuels, even with a correction for heating value, are not yet available.

(g) In knock testing, neither the air-fuel ratio nor the specific fuel consumption is usually measured. The air-fuel ratio generally used is either that giving maximum knock or maximum power and these are almost synonomous for many fuels. As matters of convenience and economy of test time, it is to be hoped that any final knock-test methods for aviation fuels will be able to avoid measurement of specific fuel consumption or air-fuel ratio.

3. *Lead Response*

The use of lead is universal at present in fuels of 83 octane number or more. This situation is likely to continue, since it is not at present possible, except on a laboratory scale, to produce fuels of 100 Army octane number without the use of lead. Some unleaded fuel of 92 Army octane number is in use but since current 100 Army octane number fuel has a full-scale value in excess of 100, and commercial isooctane which is the highest octane number commercial blending agent, is only of 98 to 99 maximum octane number (A.S.T.M. and Army), the use of an antiknock compound to secure full-scale octane numbers of 100 or more is essential. Aniline and other aromatic amines may be used as antiknock compounds instead of lead, but their cost is relatively very high and aniline is not soluble at low temperatures in straight-run gasolines and branched-chain paraffins. The low solubility of aniline may be overcome by metering it separately from the main fuel supply, and it is thus used in the form of Anilol[37] which is also a deicer. The cost of high octane numbers obtained without the use of lead has, up to the present, prevented the extensive use of unleaded isooctane blends or of straight-run gasolines plus aromatic amines.

Boyd and coworkers have made the most extensive studies of the effects of fuel type upon lead response. These studies were almost entirely concerned with pure compounds of a wide variety of chemical type.[33] Lead response is of considerable interest at present in connection with aviation fuels, and the Laboratories with which the authors are connected have made an extensive study of it.

Lead response in laboratory test engines is a function of both fuel type and engine conditions. In the early days of aviation fuel knock testing it was thought that the octane number of straight-run gasoline-lead blends was virtually independent of knock-test engine type or operating conditions and that such differences as did arise were of negligible significance. It was later realized that the differences between test methods could amount to as much as five octane numbers, but

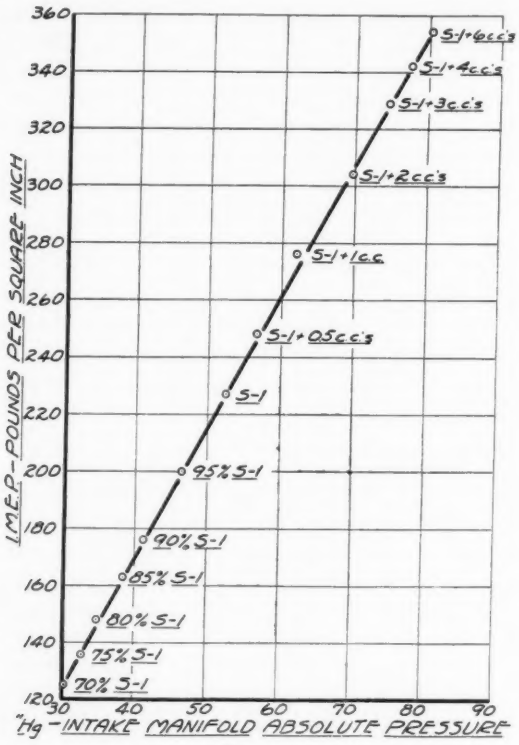

FIG. 1.

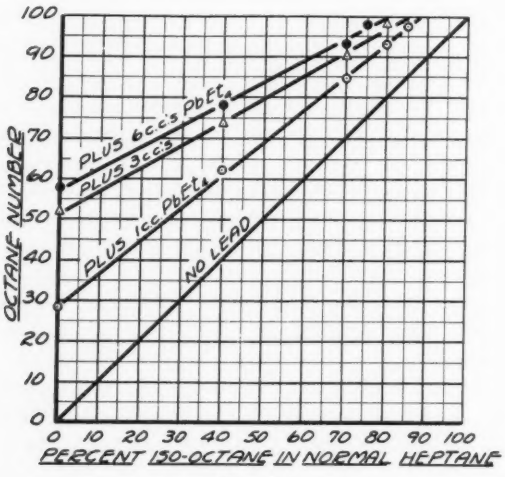

FIG. 2.

this did not have serious effects in practice since available fuels were in general of a single type with no great variation in lead content. Developments in base fuels, such as the production of commercial isooctane and synthetic gasolines having both a high antiknock value and high lead response, have changed the situation. Current 87 A.S.T.M. octane number gasolines may contain zero to 4 cu.cm. of lead, and knock-testing methods which will correctly evaluate such widely varying products have become a matter of general interest.

Lead response has often been measured in terms of

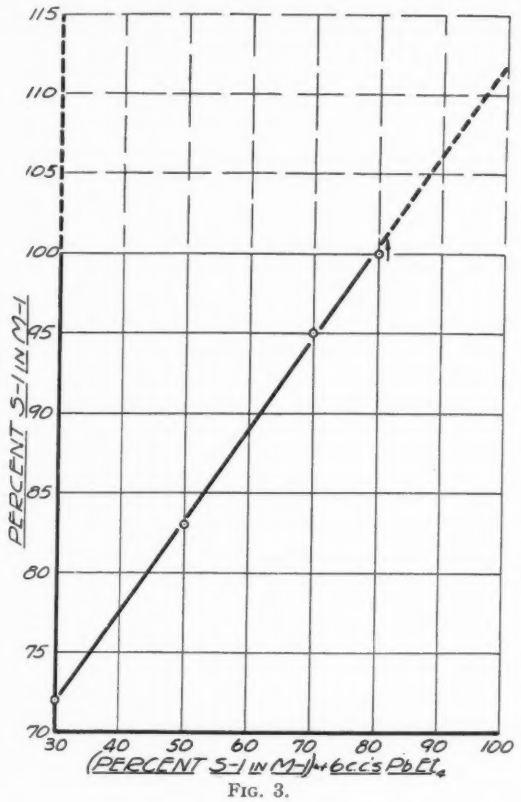

FIG. 3.

the gain in octane number for a given lead addition, without reference to the octane number of the base before the lead was added. Fig. 2 shows the effects of additions of 1, 3, and 6 cu. cm. of lead to blends of normal heptane and certified isooctane when determined by the U. S. Army method. It will be noted that the lower the octane number of the base before the lead addition, the greater the gain in octane number for a given addition. In Fig. 2 a straight line relationship is shown for octane number of the bases with constant lead addition when plotted against the octane number of the bases without lead addition. This straight line relationship for octane number of leaded *versus* unleaded base was first found for mixtures of two straight-run gasolines and later for straight-run gasoline in commercial isooctane. As a result of this known relationship, the determinations shown in Fig. 2 were carried out with the idea that they might give an idea of the probable extrapolated octane numbers of isooctane plus varying lead additions. The test method was, however, insufficiently sensitive at and over 100 octane number to give determinations which allowed of any attempt at extrapolation. The straight line relationship shown in Fig. 2 is only known to apply when both components of the bases are of sensibly similar type such as non-aromatic straight-run gasolines or branched-chain paraffins.

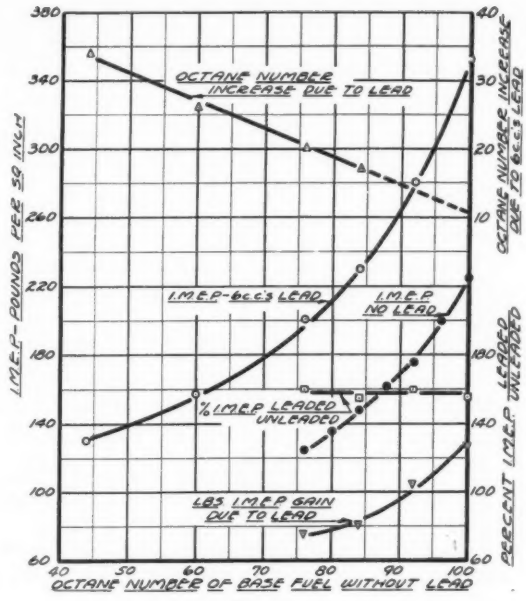
I.M.E.P.-POUNDS PER SQ INCH
OCTANE NUMBER INCREASE DUE TO LEAD
OCTANE NUMBER INCREASE DUE TO 6 C.C.'S LEAD
I.M.E.P.-6 C.C.'S LEAD
I.M.E.P. NO LEAD
% I.M.E.P. LEADED
UNLEADED
LBS I.M.E.P. GAIN DUE TO LEAD
PERCENT I.M.E.P. LEADED
UNLEADED
OCTANE NUMBER OF BASE FUEL WITHOUT LEAD

FIG. 4.

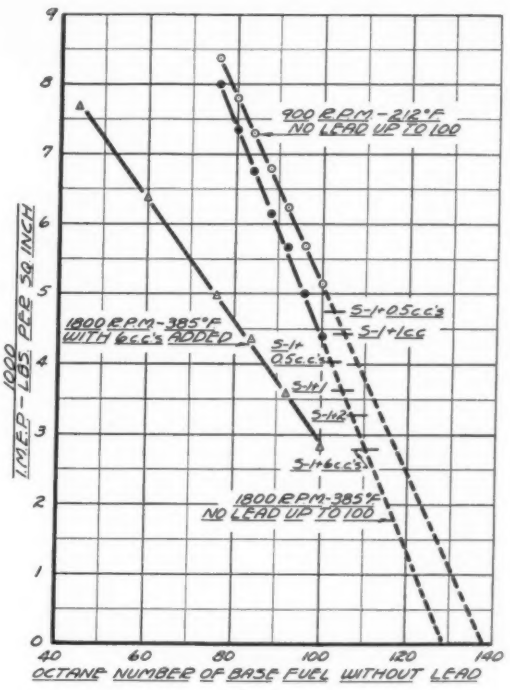

FIG. 5.

This relationship has recently been tested in a supercharged C.F.R. engine at 1800 r.p.m. and 385°F. jacket temperature and maximum knock mixture strength, with results as shown in Fig. 3. For these tests blends of C.F.R. S-1 and M-1 reference fuels were compared with varying blends of the same fuels with 6 cu. cm. of lead in each of the blends. It will be noted that S-1 plus 6 cu. cm. of lead has an extrapolated value of 112 percent S-1 which equals approximately 110 percent isooctane or 110 octane number.

In the testing which produced Fig. 3 a considerable amount of collateral data was obtained and the relationships found are shown in Fig. 4. In this figure the results are not expressed in terms of blends of C.F.R. S-1 and M-1 reference fuels but rather in terms of the A.S.T.M. octane numbers of unleaded blends of these fuels. It will be noted that the octane number gain for a 6 cu. cm. of lead addition diminishes as the octane number of the base fuel increases. The percentage gain in power resulting from the addition of 6 cu. cm. of lead is, however, constant within the limits of experimental error. The actual gain in power in pounds i.m.e.p. for a fixed lead addition increases with the octane number of the base.

In connection with Fig. 4 Homer Dedo of these Laboratories has shown that if the octane number (or percent S-1 in M-1) of the bases before lead addition be plotted against either the reciprocal of the i.m.e.p., or the reciprocal of the absolute intake air pressure, the result is a straight line relationship as shown in Fig. 5. Other data on the same supercharged engine using both unleaded and leaded blends under identical and widely different operating conditions are also shown in Fig. 5. It will be noted that the straight line relationship holds up to 100 octane number, and that at both 900 and 1800 r.p.m. the extrapolated octane number of S-1 plus 1 cc. $PbEt_4$ is about 105. From these data it appears that in the case of the $2^5/_8$-in. bore supercharged C.F.R. engine as operated at present in the Ethyl Gasoline Corporation Research Laboratories, the reciprocal of the i.m.e.p., when plotted against the octane number of leaded or unleaded base, provides an extremely useful method of checking data and engine operation. This method is also useful for predicting the limiting i.m.e.p. which should be obtained with a fuel of any given octane number when all conditions are constant except absolute pressure of the intake air. This method may prove useful in the event that isooctane plus lead is continued as the aviation reference fuel for octane numbers in excess of 100. In Figs. 4 and 5, octane numbers have been assigned to blends of C.F.R. S-1 and M-1 reference fuels by means of the approximate A.S.T.M. calibration shown in Fig. 6.

The foregoing data illustrate the general type of lead response shown by non-aromatic straight-run gasolines and synthetic branched-chain paraffin fuels. Other fuel types (cf. Table 2) show a wide diversity in lead response, and the following summarizes some of the important types and their behavior.

(a) Aromatics: The simpler types have zero response straight, and all are poor in blends.

(b) Olefins: Zero to medium response straight, all generally poor in blends.

(c) Naphthenes: Response largely unknown; cyclo-

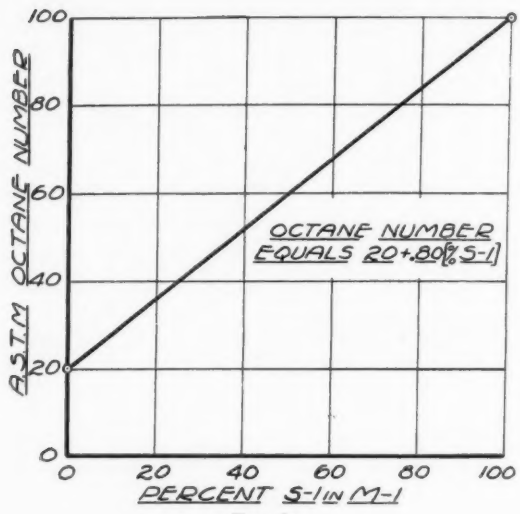

FIG. 6.

hexane is medium to poor straight, and its general behavior in blends is unknown.

(d) Oxygenated Compounds:

(*i*) *Alcohols.* Methanol: negative response in straight, negative to very slight response in blends. Isopropanol: slightly positive straight, little or no data on blends. Tertiary alcohols: limited data indicate medium to high response in blends.

(*ii*) *Ethers.* Diisopropyl ether: medium to high response straight, and high response in blends. Other branched-chain ethers: slight to high response in blends.[29]

(*iii*) *Ketones.* Acetone: slight response straight and high response in blends. Methylethyl ketone: medium to high response in blends.

(*iv*) *Summary of Oxygenated Compounds.* The oxygenated compounds may well provide a fertile field for investigation not only in respect to lead response but also in regard to antiknock properties with varied engine conditions. The alcohols appear to vary in lead response with both molecular weight and structure. The discovery of the antiknock properties of diisopropyl ether[26] served to show that the oxygenated compounds were worthy of much further study, since all ethers had been classed as proknocks. Ketones are worthy of investigation, particularly those of highly condensed structure and relatively low oxygen content, such as ditertiary butyl ketone. The behavior of acetone with almost zero response straight and high response in blends is of interest, and in outstanding contrast to benzene.

It is a somewhat curious fact that the fuels that maintain their octane number with increasing severity of knock test conditions all have marked lead response, namely, straight-run gasolines, branched-chain paraffins, and diisopropyl ether. This property is of some assistance in deciding whether a fuel is of the type currently thought (in the United States) to have the safest characteristics for aircraft use. In general, fuels whose antiknock values vary with engine test conditions show these effects with or without lead additions.

IV. The Octane Number Scale

It is quite generally realized that octane numbers are not of equal "size" or significance at different parts of the scale. Klein[1] has shown that in a full-scale engine a change from 92 to 100 Army octane number may increase permissible output by as much as 30 percent, and this indicates the magnitude of octane numbers in this portion of the scale.

Fig. 1 shows the permissible outputs in a supercharged C.F.R. engine, using a series of blends of C.F.R. S-1 and M-1 reference fuels, and S-1 lead blends. The tests were conducted at 1800 r.p.m., 385°F. jacket outlet temperature, and with maximum knock mixture strength. In Fig. 1 the fuel values below 100 octane number are expressed in terms of S-1 in M-1 and the approximate octane numbers of these blends can be determined from Fig. 6. Each 5 percent addition of S-1 to M-1 represents approximately a 4 octane number increase. The relative "size" of octane numbers in Fig. 1 is illustrated by the relative permissible power outputs for 76, 80, 96, and 100 octane numbers, which are, respectively, 100, 109, 160, and 181 percent. These figures serve as a measure of the relative importance of an octane number at the 80 and 100 octane number levels.

It is evident that means of expressing antiknock values in excess of 100 octane number is now definitely needed, since fuels with full-scale engine octane numbers of more than 100 are now in use (100 Army octane number fuels). The magnitude of octane numbers at the 100 octane number level should be given consideration in any method of expressing values in excess of 100 octane number.

The authors are somewhat reluctant even to discuss this problem at the present time, since any attempt to establish specific definitions on the basis of currently available data would be decidedly premature. However, in view of the frequent quotation of octane numbers of more than 100, consideration of extension of the scale appears to be justified.

If lead in octane is to be continued as the standard for measuring antiknock values of aviation fuel of over 100 octane number there is some argument for using it below 100. The use of clear fuels below 100 octane number and leaded fuels beyond 100 introduces a discontinuity at 100, which at the least causes difficulty in plotting data. The U. S. Army Air Corps has recognized the fact that leaded fuels may well be measured in terms of leaded reference fuels by specifying (72 isooctane + 28 heptane) plus 3 cu. cm. of lead as the refer-

ence fuel requirement in U. S. Army Specification 2-95 (92 nominal Army octane number).

In the discussion under Lead Response (Part III, Section 3) of means of extending the octane scale by the use of lead, it is not intended to suggest that any particular octane number should at present be assigned to isooctane plus any particular lead concentration. The data are merely used for the purpose of discussing means of extension of the scale with lead. It will be noted that the extrapolated octane number of isooctane plus 6 cu. cm. of lead is approximately 110 in both Figs. 3 and 5. The test method (1800 r.p.m., 385°F.) used to obtain the data gives fairly high lead response. The response of the method does not, however, appear to be in excess of that obtained in full-scale aircooled engines. Any assignment of octane numbers to isooctane plus lead will obviously require a large amount of test data obtained by methods giving high, medium, and low lead response.

In discussion of high octane fuels, reference is often made to octane numbers of 125 and more without reference to the method of deriving such numbers or to the fact that they are extrapolations without any accepted definition. Several years ago Brooks[39] at the National Bureau of Standards arrived at the conclusion that about 115 octane number represented infinity in the scale of fuel knock resistance. When this figure was arrived at, the means of investigating fuels of over 100 octane number were much less adequate than they are at present. Brooks' conclusion, however, should sound a note of caution concerning the loose use of octane numbers in excess of 100. In the authors' experience, the blending octane number for a fuel often bears no relation to the octane number of the same fuel when tested straight. Thus a fuel may have a blending octane number of 115 and yet be less than 100 octane number when not diluted. In Fig. 5 the observed data for the relationship between the inverse of the i.m.e.p. and the octane number have been extrapolated to a value of zero for the inverse of the i.m.e.p. and this shows that octane numbers of 129 and 138 represent infinity at 1800 and 900 r.p.m., respectively. The values for the observed data at 1800 r.p.m. in Fig. 5 have been extrapolated to 73 and 122 octane numbers and plotted in terms of percent power *versus* octane number in Fig. 7. While this method of extrapolation is open to criticism it is at least supported by the fact that the effects of a constant lead addition produce a uniform percent power gain when the octane number of the leaded blend is either above or below 100.

Trimble and Richardson[40] have recently reported a method of extrapolating the octane scale, using the A.S.T.M. knock-test method. Their values for octane numbers of isooctane plus lead are at variance with those shown in Fig. 5. They assign octane numbers of 106.2 to isooctane plus 0.5 cu.cm. of lead, of 109.1 to isooctane plus 1 cu. cm. of lead and, 118.7 to isooctane plus 6 cu. cm. of lead. In Fig. 5 isooctane (S-1) plus

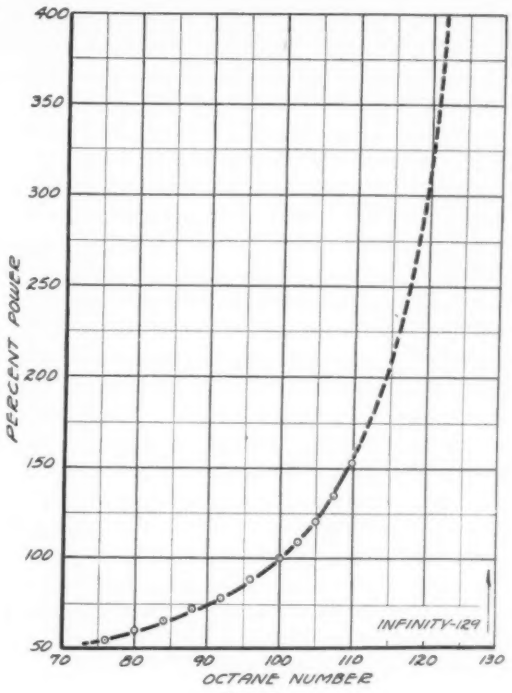

FIG. 7.

0.5 cu. cm. of lead has an octane number of about $102^1/_2$ at both 900 and 1800 r.p.m., S-1 plus 1 cu. cm. of lead has an octane number of about 105 at both speeds, and S-1 plus 6 cu. cm. of lead an octane number of about $110^1/_2$ at 1800 r.p.m.

Discussion of extrapolation of the octane scale is of value in determining the approximate nature of the scale beyond 100 octane number. If, for aviation fuels, lead in isooctane is regarded as a satisfactory means of extending the octane scale for both full-scale engine and knock-test engine use, there would appear to be no reason for expressing results in extrapolated octane numbers until such a scale has been standardized, on this continent at least, and preferably internationally.

For supercharged tests at low engine speed and low jacket temperature, isooctane plus lead does not provide a sufficiently high antiknock value for measuring the value of many fuels such as benzene and toluene. Toluene has the highest value of any single compound yet tested at 900 r.p.m. and 212°F. jacket temperature, but has zero lead response. Thus, lead in toluene cannot be used for values above toluene itself. For such tests the Laboratories of the Ethyl Gasoline Corporation have tentatively considered a ternary reference fuel system consisting of toluene, aniline, and isooctane. In this system, the high reference fuel consists of 95 percent toluene, 5 percent aniline (by volume), and the low fuel of isooctane, and the value of a test fuel would be expressed as, say, 60 percent (95 toluene, 5 aniline) plus 40 percent isooctane. This departure from con-

stant concentration of antiknock compound such as is used in leaded blends of C.F.R. S-1 and M-1 reference fuels is necessitated by the low solubility of aniline in isooctane. When the concentration of aniline in toluene is constant as is proposed, increasing aniline concentration in isooctane is accompanied by increased toluene, thus maintaining aniline solubility. A 95 to 5 toluene-aniline ratio may, of course, be less desirable than 90 to 10 but the latter may be hazardous with respect to spillage on the skin.

In a series of supercharged tests at 900 r.p.m., 212°F. jacket temperature, and 110°F. intake air temperature, toluene and 95 percent toluene, 5 percent aniline permitted 189 percent and 202 percent, respectively, of the permissible power on isooctane. Thus, the power gain due to the aniline addition was only 7 percent. The temperature of the intake air was increased to 212°F., and toluene and 95 percent toluene, 5 percent aniline then permitted 132 percent and 155 percent, respectively, of the power permissible on isooctane. At the higher intake air temperature the aniline addition resulted in a power gain of 17 percent. The relative ineffectiveness of aniline at the low intake air temperature is probably due to lack of complete vaporization.

In most tests at low engine speed and low jacket temperature, toluene in isooctane, without addition of aniline, provides a satisfactory extension of the scale beyond 100 octane number.

V. Water Tolerance and Latent Heat

In addition to octane number, two important (and in part related) characteristics of aircraft fuels are water solubility and latent heat of evaporation. Data for these are included in Tables 1 and 2.

1. Carburetor and Fuel System Freezing

Carburetor deicing is of pronounced interest at present and when this is to be accomplished by deicing liquids, the fuels which are completely miscible with water are an obvious solution. Methanol, ethanol, propanol, isopropanol, and acetone are all completely water soluble and have possibilities as deicing fuels. Diisopropyl ether has been said to have deicing properties.[27] While its solubility in water is of the order of 1000 times that of gasoline this does not appear to be sufficient to give any considerable deicing effect. Should diisopropyl ether prove to be an efficient deicer, present physical concepts of deicing mechanism will need considerable revision.

Data as to solubility of water in the fuel and of solubility of the fuel in water have been included since they have bearing on fuel system freezing and carburetor deicing. Fuel system freezing with fuels of low freezing point is largely a function of the tendency of the fuel to dissolve water at normal temperature and to throw this water out of solution as the fuel temperature is reduced in flight, rather than of the total water content of the fuel. However, in the case of fuels which dissolve little water, data as to the amount of water they will dissolve provide a reasonable measure of their tendency to throw it out with reduction of temperature and hence to cause fuel system freezing. Data as to solubility of water in the fuels are meager and none too reliable. The figures in Table 1 for benzene and diisopropyl ether appear to be in conflict when considered in light of Buc and Aldrin's[26] data comparing diisopropyl ether-gasoline blends with similar gasoline-aromatic blends. Aromatics dissolve about 10 times as much water as normal gasolines and automobile experience in Europe indicates that benzol blends produce much greater water accumulation in the fuel system than do normal gasolines.

From the standpoint of fuel system freezing either minimum or complete solubility of water in the fuel would appear desirable. With an increasing tendency to flight at high altitude the problem of fuel system freezing is likely to become of added moment. Operation at high altitude adds considerably to vapor lock troubles which can be controlled largely by reduction of fuel temperature. Reduction of fuel temperature by the use of fuel coolers will bring in its train an increased tendency to deposition of water in the fuel system and consequent freezing.

Aniline mixed with alcohols and known as Anilol[37] is in use on this continent as a combination antiknock and deicing mixture. This is used to produce emergency antiknock effects for take-off and for single engine operation, or may be used continuously as a deicer when weather conditions require it. It is not used in admixture with the fuel but is metered separately and is usually automatically cut in for take-off.

2. Latent Heat of Evaporation

It is known that a high latent heat for a given heat input will reduce mixture temperature and will lower cylinder and piston temperatures if not accompanied by undesirable combustion characteristics. With the present demand for both abnormal output and pronounced cylinder cooling effects during the short period involved in take-off, alcohols with their high latent heats have possibilities as take-off fuels since they give the same effects on mixture density as a supercharger intercooler without the continuous handicaps of weight and drag due to the intercooler. In Europe methanol has proved to be of considerable value in some types of liquid-cooled racing aircraft engine. Whether this is due to antiknock characteristics or to mixture cooling effects in these cases is not known.

Alcohols in general tend to produce pre-ignition in engines with high cylinder wall temperatures. This tendency can, however, be reduced by the addition of water. Blends of isopropanol with water may be equal to methanol both in respect to gross heating value and latent heat and are likely to be a great deal better in respect to pre-igniting tendency. Isopropanol-water

blends have a slight positive lead response in contrast to methanol which is strongly negative. Thus isopropanol-water blends are likely to be of advantage for take-off fuels in contrast to methanol, under conditions where take-off is accomplished with a normal leaded fuel plus a separately metered supply of alcohol. For take-off, alcohols apparently have the advantage that mixture strength can be made abnormally rich (in respect to the chemically correct mixture) for engine cooling purposes without serious reduction of output such as is experienced with normal hydrocarbon fuels when operating at about 50 percent rich.[36]

The so-called antiknock effects of water have not been dealt with. Available data do not extend much beyond the knowledge that its effects are pronounced. Hubner and Egloff[27] have pointed out that the known effects may be due either to cooling or to chemical action. It is the authors' opinion that the cooling effects of water are sufficient to explain its action in inhibiting both knock and pre-ignition. Campbell[41] and Prescott[42] have both dealt with full-scale effects of water.

3. *Effects of Latent Heat on Mixture Temperature and Output*

(a) In view of the significance of latent heat values, some approximate calculations of mixture temperatures have been made to show the relative effects of evaporation of a normal gasoline and of a combination consisting of normal gasoline plus isopropanol-water, the latter having very high latent heat.

The following assumptions are made:

(*i*) *Engine.* The supercharged air is at a temperature of 230°F. before the addition of fuel. The fuel temperature is 100°F.

(*ii*) *Gasoline Operation.* The gross heating value is 20,600 B.t.u. per lb. The latent heat of evaporation is 145 B.t.u. per lb. The specific heat is 0.55. The specific fuel consumption is 0.75 lb. per b.h.p.-hr. The air fuel ratio is 10 to 1.

(*iii*) *Bifuel Operation.* The same gasoline as in (*ii*) is used. The gross heat input in fuel is the same as in (*ii*), *i.e.*, 15,500 B.t.u. per b.h.p.-hr. The gasoline specific fuel consumption is 0.5 lb. per b.h.p.-hr. The secondary fuel is 80 percent isopropanol 20-percent water (by volume; approximately equals 76 percent and 24 percent, respectively, by weight). The gross heating value is 11,000 B.t.u. per lb. The latent heat of evaporation is 460 B.t.u. per lb. The specific heat is 0.66.

To give the same heat input as with gasoline in (*ii*) will require that 0.0667 lb. gasoline and 0.0623 lb. 80 to 20 isopropanol-water per lb. of air be used. This equals 0.129 lb. fuel per lb. of air or an air-fuel ratio of 7.75 to 1. Assuming no change in combustion efficiency the gasoline-isopropanol-water mixture will give a specific fuel consumption of 0.98 lb. per b.h.p.-hr.

(*iv*) *Sensible and Latent Heat Effects.* Assuming complete evaporation (which recent full-scale work indicates to be doubtful even at high mixture temperatures) the two sets of fuel combinations will produce the following approximate effects.

The sensible heat and latent heat of evaporation of the gasoline when added to the air at 10 to 1 air-fuel ratio, result in an approximate mixture temperature of 157°F. or 617°F. absolute. The gasoline-isopropanol-water additions to the air result in an approximate mixture temperature of 78°F. or 538°F. absolute.

Charge density will be inversely proportional to absolute temperature. Thus the ratio of charge density for the two cases will be 617/538 or 115 per cent.

(b) Experimental Investigation. Comparative tests of: a 100 Army octane number leaded fuel (80 percent S-1, 20 percent M-1 with 4 cu. cm. of lead in the blend), the 100 octane leaded fuel plus a separately metered supply of 80 percent isopropanol—20 percent water, and 80 percent isopropanol—20 percent water alone, have been carried out in a supercharged C.F.R. engine. These tests were carried out with the following conditions: 1800 r.p.m., jacket inlet temperature 320°F., jacket outlet temperature variable; cooling with a triethyleneglycol-water mixture with 385°F. boiling point, circulated at a rate of 5 liters per minute; absolute intake air pressure 50.2 in. Hg; intake air temperature 225°F.

The engine was first set at the boost pressure producing light knock with maximum knock mixture strength on the 100 octane leaded fuel. With the boost held constant the fuel supply rate was first increased and then decreased until operation became unsteady due to excessive enriching and leaning off. In the second test the engine was set at maximum knock mixture strength on the 100 octane fuel at the same boost as in the first test. Isopropanol-water was then added to the mixture by a separate metering system and this supply was progressively increased until operation became unsteady. As the isopropanol-water supply increased, the volumetric efficiency also increased as evidenced by a greater air supply being required to maintain constant intake air pressure. In the third test isopropanol-water was used alone, from very rich to very lean.

The data for the three tests are shown in Fig. 8. In this figure it will be noted that the temperatures of the thermal plug, spark plug gasket, cylinder head, and cylinder base, all rise or fall uniformly with enriching or leaning on any given fuel combination, and that the temperature rise of the cooling liquid from inlet to outlet also follows the trend of cylinder temperatures. The cooling liquid temperature rise is not a complete measure of heat rejected to the cylinder walls since a considerable heat loss occurs by air-cooling of the outside of the cylinder jacket. This heat loss is probably

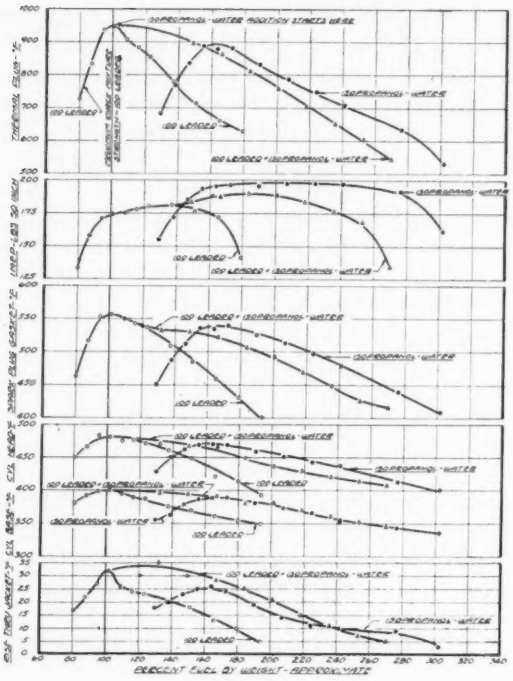

FIG. 8.

almost constant and the cooling liquid temperature rise figures would become a measure of heat rejected, by the addition of an unknown constant. Operation at constant jacket inlet temperature with constant volume flow of cooling liquid and non-evaporative cooling, represents the nearest approach possible in the C.F.R. engine to the cooling conditions of an air-cooled full-scale engine. In the air-cooled full-scale engine with constant cooling-air velocity, the supply of cooling medium may be considered as constant. In any liquid-cooled engine effective cooling may be greatly increased at local hot-spots by evaporative effects. In the case of triethylene glycol-water mixtures, however, these evaporative effects are known to be very slight.

In Fig. 8 it will be noted that maximum knock and maximum power mixture strengths are somewhat widely separated with the 100 Army octane fuel. Fig. 8 shows that the addition of isopropanol-water to 100 octane gasoline, or its use alone, has definite advantages in respect to operation at mixtures rich enough to produce pronounced cylinder temperature reductions. The wide differential between the mixture strength producing maximum cylinder temperature and that giving maximum power in the case of isopropanol-water alone is of distinct interest.

The observed increase of power with the isopropanol-water addition to 100 octane gasoline would, when compared to the calculations in **(a)** above, indicate that evaporation is incomplete at the time of intake valve closing. If evaporation is incomplete at the time of intake valve closing, the latent heat effect is lost as regards charge density and is probably largely available for cylinder wall cooling. These tests were not run under the identical conditions assumed in **(a)** above. In the authors' opinion the tests do, however, serve to show that leaded gasoline and isopropanol-water are not incompatible from the antiknock standpoint and that considerable emergency cylinder cooling for take-off can probably be obtained by the use of isopropanol-water mixtures.

In Fig. 8 the data for weight of fuel consumed are only approximate and are derived from calibrations of the fuel metering pumps. These calibrations were not obtained at the same time as the data in Fig. 8. The data should not be used to calculate the relative air-fuel ratios for maximum knock, etc., for the various fuel combinations.

(c) Service Use of High Latent Heat Fuels. The use of fuels such as isopropanol-water can only be considered for take-off since the penalty in weight of fuel consumed is only permissible for very short periods. For a similar weight consumption, gasoline and water would give somewhat more mixture cooling effect than the isopropanol-water combination discussed above. Water alone, would however, rarely be admissible on this continent on account of freezing, whereas isopropanol-water is a deicing fuel.

Alcohols and alcohol-water mixtures are very corrosive to some magnesium alloys. The use of such fuels therefore requires caution in respect to both fuel and induction systems.

If isopropanol-water or other water blends are to be used alone for take-off, it is the authors' opinion that this should be done by gradually reducing the supply of gasoline while the alcohol-water mixture supply is increased with throttle opening. It is suggested that the supply of alcohol-water should not start until the power output is somewhat above that corresponding to cruising. Operation with alcohol-water mixtures at idling and at low mean effective pressures is irregular and rapid plug fouling is usually experienced, generally requiring plug removal or replacement. Plug fouling with alcohol-water is probably the result of such fuels being immiscible with lubricating oil and in part due to the fact that they short circuit the spark-plug gaps.

VI. Conclusions

In considering the antiknock effects shown in Table 2 it may be well to bear in mind that experience in the United States has shown that the safest fuels for general service are those whose octane numbers are least subject to change with engine test conditions. Thus, straight-run gasolines or their blends with branched chain paraffins are much less open to doubt than gasoline blends with aromatics, alcohols, or olefins. Any fuel which shows the characteristic of a falling octane number with increase of speed, cylinder temperature, or mixture temperature in knock testing may be subject to doubts as to its full-scale reliability. These views are

not accepted in Europe and other parts of the world, and change of engine type in the United States may cause modification.

By and large, in the light of present knowledge, straight-run gasolines (or synthetic gasolines of similar properties) and branched-chain paraffins are the outstandingly useful aviation fuels. They are stable in storage, have very low water solubility, give the highest heating values, and their octane numbers are subject to only a slight variation with engine type or operating conditions.

While the antiknock properties of the water-soluble fuels such as alcohols and ketones may appear attractive, such fuels are less desirable than hydrocarbons for general service use. In blends with hydrocarbons, separation of the components due to reduction of temperature or contact with water is an ever present hazard. Separate metering of hydrocarbon and water-soluble fuel, of course, eliminates the separation troubles likely with blends. The combined oxygen in the water-soluble fuels is a definite handicap with respect to specific cruising fuel consumption in cases where maximum load carrying capacity and range are required. In some types of operation, however, take-off output and fuel availability may be more important than range, and in such cases oxygenated fuels may find a field of application.

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Supersonic Flow Over an Inclined Body of Revolution

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SUMMARY

A first approximation is obtained for the side force or the lift of a body of revolution inclined in a supersonic flow from the linearized equation of motion of compressible fluids. It is shown that the lift at any fixed Mach's number is directly proportional to the angle of attack of the body. The case of the cone is calculated in detail and a general method using step-wise doublet distribution is developed for a pointed projectile.

THE aerodynamic forces acting on a projectile can be divided into three parts: the resistance or drag in the direction of the axis of the body, the lift in the direction perpendicular to the axis of the body, and the forces due to the rotation of the body (Magnus effect). The first component, the resistance, is, of course, the most important one, because it is the predominating factor in determining the range of the projectile. However, in the case of an actual projectile, inclination and rotation are always present, and, therefore, accurate calculation of range is impossible without considering the second and third components of aerodynamic forces, *i.e.*, the lift and the forces due to rotation of the body. von Kármán[2] suggested that his method of sources for the linearized hydrodynamical equation of axial flow[1] over a slender body of revolution can be generalized to the case in which the projectile is inclined to the flight path. This is carried out in the present paper. Strictly speaking, the solution is applicable only to a very slender body inclined at a small angle to the flight path, because second order quantities of the disturbance due to the presence of the body are neglected. However, for the case of axial flow over a cone, von Kármán-Moore's first approximation[1] differs very little from the exact solution of Taylor and Maccoll[3] for vertex angles up to 40°. Therefore, it is expected that the first approximation of the lift force as obtained in this paper can be applied to a pointed projectile with fair accuracy. This is substantiated by the example shown at the end of this paper.

If ϕ is the potential of the small disturbance velocity due to the presence of a body of revolution whose axis coincides with the x-axis, then the linearized equation of motion of compressible fluids in cylindrical coordinates x, r, and θ is

$$\left(1-\frac{V^2}{c^2}\right)\frac{\partial^2\phi}{\partial x^2}+\frac{1}{r}\frac{\partial\phi}{\partial r}+\frac{\partial^2\phi}{\partial r^2}+\frac{1}{r^2}\frac{\partial^2\phi}{\partial\theta^2}=0 \qquad (1)$$

In this equation, V is the velocity of the undisturbed flow for which the velocity of sound is c. If the direction of the undisturbed flow coincides with the axis of the body, then ϕ is independent of θ, and Eq. (1) reduces to

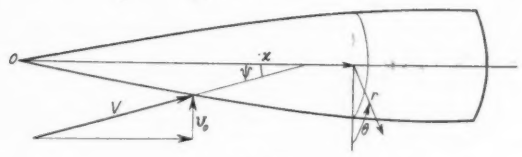

FIG. 1.

$$\left(1-\frac{V^2}{c^2}\right)\frac{\partial^2\phi}{\partial x^2}+\frac{1}{r}\frac{\partial\phi}{\partial r}+\frac{\partial^2\phi}{\partial r^2}=0 \qquad (2)$$

The solution of this equation when the velocity of the undisturbed flow is greater than the velocity of sound, is the same as that for a two-dimensional wave diverging from a center. It was obtained by Levi-Civita[4] and by H. Lamb.[5] von Kármán and Moore[1] applied it to the present case and showed that it can be expressed as a source distribution given by the potential

$$\phi_1=\int_{\cosh^{-1}(x/\alpha r)}^{0} f_1\,(x-\alpha r\cosh u)du \qquad (3)$$

where $\alpha=\sqrt{(V/c)^2-1}$. Analogy with a similar case of flow of an incompressible fluid leads one to expect the solution of Eq. (1) to be a doublet distribution given by the potential

$$\phi_2=-\alpha\cos\theta\int_{\cosh^{-1}(x/\alpha r)}^{0} f\,(x-\alpha r\cosh u)\cosh u\,du \qquad (4)$$

This can be shown to be true, because, if the solution of Eq. (1) is of the form

$$\phi_2=\cos\theta\,F(x,r)$$

then Eq. (1) reduces to

$$\left(1-\frac{V^2}{c^2}\right)\frac{\partial^2F}{\partial x^2}+\frac{1}{r}\frac{\partial F}{\partial r}+\frac{\partial^2F}{\partial r^2}-\frac{F}{r^2}=0 \qquad (1a)$$

Differentiation of Eq. (2) with respect to r gives

$$\left(1-\frac{V^2}{c^2}\right)\frac{\partial^2}{\partial x^2}\left(\frac{\partial\phi}{\partial r}\right)+\frac{1}{r}\frac{\partial}{\partial r}\left(\frac{\partial\phi}{\partial r}\right)+\frac{\partial^2}{\partial r^2}\left(\frac{\partial\phi}{\partial r}\right)-\frac{1}{r^2}\left(\frac{\partial\phi}{\partial r}\right)=0 \qquad (2a)$$

Comparing Eq. (1a) with Eq. (2a), it is easily seen that

Eq. (4) is a solution of Eq. (1). The function f has to be determined by the boundary condition

$$v_0 = \frac{1}{\cos\theta}\left(\frac{\partial\phi}{\partial r}\right)_{r=R} = -\alpha^2 \int_{\cosh^{-1}(x/\alpha r)}^{\pi} f'(x-\alpha R\cosh u)\cosh^2 u\, du \quad (5)$$

where v_0 is the normal component of the velocity V of the undisturbed flow, and R is the radius of the body.

The complete solution of flow over an inclined body of revolution is then obtained by superimposing a cross-flow upon an axial flow, *i.e.*, $\phi = \phi_1 + \phi_2$. This solution was also suggested independently by C. Ferrari.[6]

From the velocity potential ϕ, one can calculate the pressure distribution over the body and then the aerodynamic forces. However, since the theory is based upon the linearized equation, the cross product terms of derivatives of ϕ_1 and ϕ_2 in the pressure calculation can be neglected. Therefore the following simplification results: The resistance or drag can be calculated from the axial flow alone and the lift can be separately computed from the cross flow. Since the resistance was calculated before,[1] the following treatment is concerned only with the lift force. Retaining only first order terms, the lift acting in a direction perpendicular to the axis of the body and the moment about the vertex are thus

$$\begin{aligned} L &= \int_0^{\pi}\int_0^{\infty} \Delta p\, r d\theta \cos\theta\, dx \\ &\approx 2\rho V \int_0^{\pi}\int_0^{\infty} \frac{\partial\phi_2}{\partial x}\, r\cos\theta\, d\theta\, dx \qquad (6) \\ M &= \int_0^{\pi}\int_0^{\infty} \Delta p\, r d\theta \cos\theta\, x dx \\ &\approx 2\rho V \int_0^{\pi}\int_0^{\infty} \frac{\partial\phi_2}{\partial x}\, xr\cos\theta\, d\theta\, dx \end{aligned}$$

where Δp is the difference between the pressure at the surface of the body and that of the undisturbed flow and ρ is the density of the fluid in the undisturbed flow.

Eq. (5) is a non-homogeneous linear integral equation in f which does not have a general solution of simple form. However, it is interesting to see how Eq. (5) simplifies in the limiting case when the radius of body approaches zero. It is convenient here to use $\xi = x - \alpha r\cosh u$ as the independent variable, then Eq. (5) becomes

$$\begin{aligned} v_0 &= \frac{1}{R^2}\int_0^{x-\alpha R} \frac{f'(\xi)\,(x-\xi)^2 d\xi}{\sqrt{(x-\xi)^2 - \alpha^2 R^2}} \qquad (5a) \\ &\approx \frac{1}{R^2}\int_0^{x-\alpha R} f'(\xi)\,(x-\xi) d\xi = \frac{1}{R^2}\int_0^{x} f(x)\, dx \end{aligned}$$

where $f(0)$ is put equal to zero, assuming that the projectile has a pointed nose. Since the cross-sectional area of the body of revolution is $S = \pi R^2$, Eq. (5a) gives

$$f(x) = (v_0/\pi)\,(dS/dx) \qquad (7)$$

Substituting into Eq. (6), the lift force is then

$$L = 2\rho V \int_0^{\pi}\int_0^{\infty} \frac{v_0\cos^2\theta}{\pi}\frac{dS}{dx}\, d\theta\, dx = \rho v_0 V A_b$$

where A_b = area of the base section of the body. Hence the lift coefficient can be evaluated as

$$C_L = \frac{L}{\rho/2\ V^2 A_b} = 2\frac{v_0}{V} \approx 2\psi \qquad (8)$$

in which ψ = angle of attack of the body.

The moment arm d, *i.e.*, the distance between the point of application of the resultant lift force and the vertex can be obtained by dividing the moment computed from Eq. (6) by the lift force, and thus

$$d = [A_b - (A_m/A_b)]\, l \qquad (10)$$

where A_m = area of the mean section of the body; *i.e.*, the volume of the body divided by its length, l.

The results of Eq. (8) and Eq. (9) are identical to those found in Munk's theory of airships.[7] At first sight, this might be surprising. However, if the radius of the body approaches zero as assumed, the cross-flow pattern is the same as that for an infinitely long circular cylinder moving with its axes perpendicular to the flow. Therefore, in every plane perpendicular to the axis of the body, the flow can be considered as two dimensional, *i.e.*, it is independent of the variable x. Hence Eq. (1) reduces simply to

$$\frac{\partial^2\phi}{\partial r^2} + \frac{1}{r}\frac{\partial\phi}{\partial r} + \frac{1}{r^2}\frac{\partial^2\phi}{\partial\theta^2} = 0 \qquad (1b)$$

This is immediately recognized as the equation of motion for two-dimensional flow of incompressible fluids, which is the basis of Munk's theory.

Due to this two-dimensional character of the flow, the distribution of doublets is not effected by the change in Mach's number, which is only connected with the independent variable x, and, therefore, the lift coefficient and the moment arm are also independent of Mach's number as shown by Eq. (8) and Eq. (9). This can also be seen from the fact that when r approaches zero, the variable $\xi = (x - \alpha r\cosh u) \to x$ and thus the effect of α, which is a function of Mach's number, is removed. To study the effect of Mach's number on the lift of the body, one has to go back to Eq. (5). To avoid the difficulty of solving this integral equation, the "indirect method" of solution can be employed, *i.e.*, take a function f and determine the necessary shape of the body to comply with this function f.

Taking the simplest case

$$f(x - \alpha r\cosh u) = K(x - \alpha r\cosh u)$$

where K = a constant. Then

$$\begin{aligned} \phi_2 &= -K\alpha\cos\theta \int_{\cosh^{-1}(x/\alpha r)}^{0} (x - \alpha r\cosh u)\cosh u\, du \\ &= K\alpha\cos\theta\left\{\frac{x}{2}\sqrt{\left(\frac{x}{\alpha r}\right)^2 - 1} - \frac{\alpha r}{2}\cosh^{-1}\frac{x}{\alpha r}\right\} \qquad (4a) \end{aligned}$$

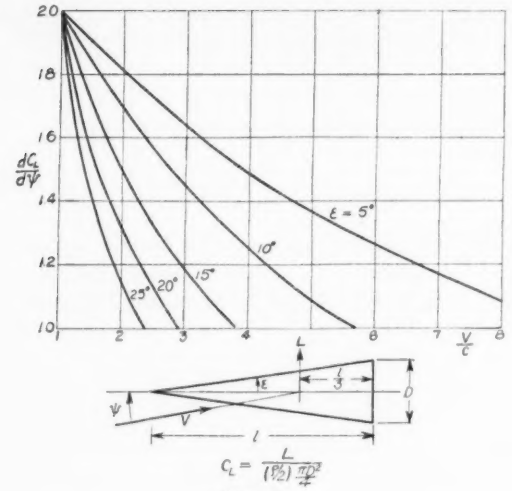

FIG. 2.

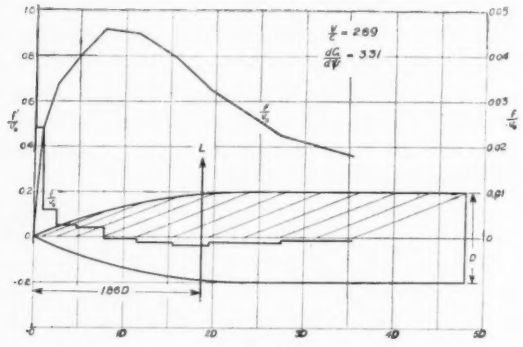

FIG. 3.

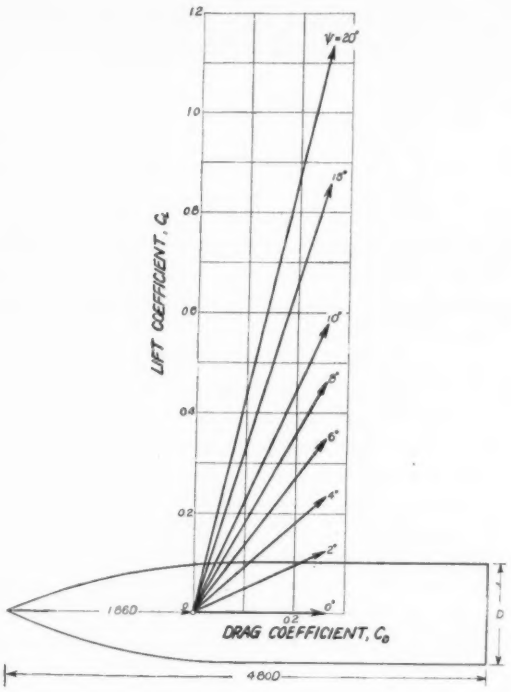

FIG. 4.

And the boundary condition reduces to

$$v_0 = \frac{K\alpha^2}{2}\left\{\left(\frac{x}{\alpha R}\right)\sqrt{\left(\frac{x}{\alpha R}\right)^2 - 1} + \cosh^{-1}\left(\frac{x}{\alpha R}\right)\right\}$$

Therefore, the solution, Eq. (4a), is evidently a solution for a cone with half vertex angle ϵ, if $\cot \epsilon = (x/R)$. By putting $(\cot \epsilon/\alpha) = \zeta$ the boundary condition can be written in the form

$$v_0 = (\alpha^2 K/2)\{\zeta\sqrt{\zeta^2 - 1} + \cosh^{-1}\zeta\} \qquad (5b)$$

For any given value of vertex angle and Mach's number, the corresponding value of K can be obtained from Eq. (5b). Then the lift coefficient can be calculated by using Eq. (6) and it is found to be

$$C_L = K_1\psi \qquad (10)$$

where $K_1 = 2\zeta\sqrt{\zeta^2 - 1}/(\zeta\sqrt{\zeta^2 - 1} + \cosh^{-1}\zeta)$. In the limiting case when ϵ approaches zero, $K_1 \to 2$ which agrees with Eq. (8). Similarly from Eq. (6) the moment coefficient is

$$C_M = \frac{\text{Moment about Vertex}}{(\rho/2)\ V^2\ A_b\ l} = \frac{2}{3}K_1\psi \qquad (11)$$

which satisfies Eq. (9).

Both Eq. (8) and Eq. (10) show that the lift at a given Mach's number is proportional to the angle of attack of the body. This is a general characteristic of flow around a body without separation. If the fluid separates from the body and creates a "dead water" region on the lee side of the body, then the lift will be proportional to the square of the angle of attack as was shown by W. Bollay.[8] The problem, whether the fluid separates or not, can only be answered by experiments. From the experimental data now available,[9] it seems that the flow is continuous without separation, and, therefore, the lift is proportional to the angle of attack of the body.

Fig. 2 is the result of computation using Eq. (10). Calculations were carried out for values of $K_1 \geqq 1$, because the value of $K_1 = 1$ corresponds to $\epsilon = \beta$, where β is the wave angle. For $K_1 < 1$ it is found that $\beta < \epsilon$. This means that the wave angle is smaller than the vertex angle which is, of course, impossible. Therefore, $K_1 = 1$ marks the limit of validity of this solution. In fact, even when K_1 is near to 1, the solution must be considered as qualitative only, since in this region the effect of the surface of the body on the shock wave cannot be neglected.

To generalize the solution for a body of revolution with a sharp point at the origin and cylindrical shape at infinity, it is simplest to use a step-wise doublet distribution. Consider the points $P_1, P_2, \ldots P_n, \ldots P_N$ of the meridian line of the body, and designate their coordinates by $x_1, R_1; x_2, R_2; \ldots; x_n, R_n, \ldots; x_N, R_N$ and the corresponding values of $x - \alpha R$ by $\xi_1, \xi_2, \ldots, \xi_n, \ldots \xi_N$. Then the boundary condition of Eq. (5) can be written as

$$v_0 = -\frac{\alpha^2}{2}\sum_{i=1}^{n} K_i \left\{ \left(\cosh^{-1}\frac{x_n - \xi_{i-1}}{\alpha R_n} - \cosh^{-1}\frac{x_n - \xi_i}{\alpha R_n} \right) + \left(\frac{x_n - \xi_{i-1}}{\alpha R_n}\sqrt{\left(\frac{x_n - \xi_{i-1}}{\alpha R_n}\right)^2 - 1} - \frac{x_n - \xi_i}{\alpha R_n}\sqrt{\left(\frac{x_n - \xi_i}{\alpha R_n}\right)^2 - 1} \right) \right\} \tag{5c}$$

This condition actually gives a set of N equations to determine the N constants K_i. This set of equations can be solved rather easily because each following equation in the set only contains one more K_i which does not appear in the preceding one of the set. When K_is are determined, the lift can be calculated by using Eq. (6) The lift and moment coefficients are thus obtained as

$$C_L = \frac{2\psi}{\alpha}\sum_{n=0}^{n=N}\frac{(x_{n+1} - x_n)}{R_N}\left(\frac{R_{n+1} + R_n}{R_N}\right)\left\{\sum_{i=0}^{i=n} K\left[\sqrt{\left(\frac{x_n - \xi_{i-1}}{\alpha R_n}\right)^2 - 1} - \sqrt{\left(\frac{x_n - \xi_i}{\alpha R_n}\right)^2 - 1}\right]\right\}$$

$$C_M = \frac{2\psi}{\alpha l}\sum_{n=0}^{n=N}\left\{\frac{x_{n+1} + 2x_n}{3} + \frac{(x_{n+1} - x_n)}{3}\left(\frac{R_{n+1}}{R_{n+1} + R_n}\right)\right\}\frac{(x_{n+1} - x_n)}{R_n}\left(\frac{R_{n+1} + R_n}{R_N}\right)\times$$
$$\left\{\sum_{i=0}^{i=n} K_i\left[\sqrt{\left(\frac{x_n - \xi_{i-1}}{\alpha R_n}\right)^2 - 1} - \sqrt{\left(\frac{x_n - \xi_i}{\alpha R_n}\right)^2 - 1}\right]\right\} \tag{12}$$

where P_N is the last point on the meridian line, R_N is the base radius, and l is length of the body.

Fig. 3 is the result of the calculation using Eq. (12) for a body of revolution with "6-caliber head" and total length of 4.8 calibers, when it is traveling with a velocity 2.69 times that of sound ($\alpha = 2.5$). The lift coefficient is considerably higher than that of a cone at the same angle of attack and at the same Mach's number, evidently due to the cylindrical part of the body. The position of the resulting lift force is also shown in the figure. Since, as mentioned before, lift and drag are independent in the first order approximation, the calculated lift coefficient can be combined with the drag coefficient taken from experiments and thus give some information on the magnitude and direction of the resulting force. Fig. 4 shows the method applied to this projectile with the drag coefficient taken from Kent's experiment.[10]

If the projectile has a length of 4.34 diameters instead of 4.8 diameters and has the same nose shape, and, if its center of gravity is located at a point 2.68 diameters back of the nose, then the calculated moment about the center of gravity can be expressed as $M = \rho V^2 \times R_N{}^3\psi f(V/c)$ where $f(V/c) = 9.35$ for $(V/c) = 2.69$. This compares closely with the value $f(V/c) = 10.7$ extrapolated from R. H. Fowler's experiment,[9] for a projectile of the same proportions. This shows that the theory developed in this paper can be applied to a projectile with fair accuracy.

The author expresses his gratitude to Professor Th. von Kármán for suggesting the subject and for his frequent help during the course of the work.

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Performance Tests of Navy Radio Meteorograph System[1]

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ABSTRACT

Improvements of the Navy radio meteorograph system are described and the results are given of a series of 50 simultaneous radio meteorograph and aerograph soundings under typical service conditions. The improvements have resulted in a simplified calibrating and operating procedure which affords greater accuracy of performance while at the same time increasing the allowable manufacturing tolerances. The results of the simultaneous soundings show that the radio meteorograph is sufficiently accurate to warrant its early adoption for routine use.

I. INTRODUCTION

IN A PREVIOUS paper,[2] a radio-meteorograph system developed for use by the Aerological Service of the U. S. Navy Department was described. During the past year the component parts of the system have been materially improved and the performance of the system has been determined through the medium of simultaneous radio meteorograph and aerograph ascents under typical service conditions. The present paper gives an account of the improvements effected and an analysis of the test results. The results demonstrate conclusively that the radio meteorograph is ready for routine daily use in place of the present airplane method of taking upper-air soundings.

II. BRIEF REVIEW OF THE NAVY RADIO METEOROGRAPH SYSTEM

A brief review of the method of radio meteorography employed is desirable for a clear explanation of the improvements effected The modulating frequency of the carrier wave emitted by the radio transmitter is controlled by two variable resistors, in the meteorograph unit, which vary in accordance with the air temperature and humidity, respectively, and by a third, fixed resistor. The temperature resistor consists of a small capillary tube filled with an electrolyte having a high temperature coefficient of resistance, while the humidity resistor consists of a wire-wound unit having a variable tap, the position of which is controlled by the contraction or expansion of a hair element. The modulating frequency is normally a function of the temperature to which the capillary thermometer is exposed.

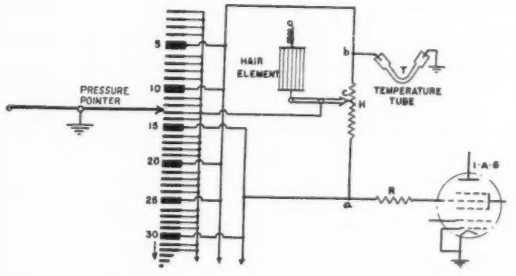

FIG. 1. Schematic view of the Navy radio meteorograph.

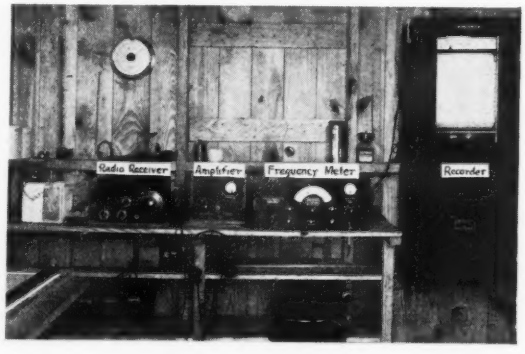

FIG. 2. Ground station receiving and recording equipment.

However, as the balloon carries the radio meteorograph upward, a pointer (actuated by the pressure diaphragm) periodically makes contact with conducting strips electrically connected to the three resistors of the modulating circuit. The net resistance remaining in circuit is thereby modified so that the modulating frequency corresponds to the value of the relative humidity or to two fixed (index) values useful in evaluating the record. A previous calibration of the switching element permits evaluation of the barometric pressure corresponding to the instants at which the pointer contacts the conducting strips. The switching operations are clearly indicated in Fig. 1 and are explained in reference (1).

At the receiving station (see Fig. 2) an electronic-frequency meter is connected to the output of the radio receiving set and converts the received signal of varying audio frequency into a direct current the value of which is proportional to the frequency. This current operates a high-speed recording milliammeter. The record obtained constitutes a plot of temperature and humidity as abscissas against pressure as ordinates.

[1] Publication approved by the Director of the National Bureau of Standards of the U. S. Department of Commerce.

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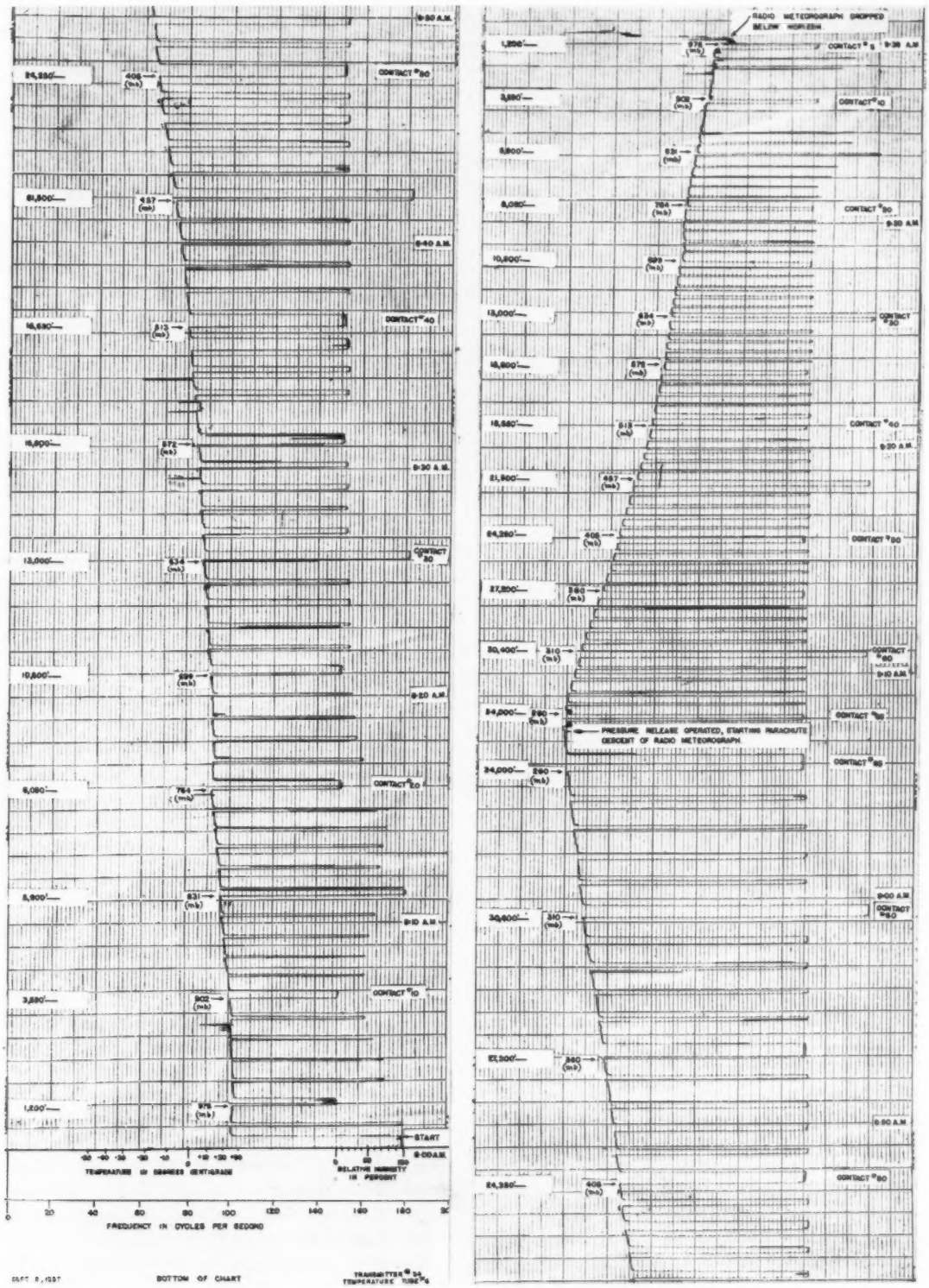
START
TEMPERATURE IN DEGREES CENTIGRADE
RELATIVE HUMIDITY IN PERCENT
FREQUENCY IN CYCLES PER SECOND
BOTTOM OF CHART
RADIO METEOROGRAPH DROPPED BELOW HORIZON
PRESSURE RELEASE OPERATED, STARTING PARACHUTE DESCENT OF RADIO METEOROGRAPH

FIG. 3. Sample ascension record.

A typical record is shown in Fig. 3. Because of the length of chart, this record was photographed in two sections. The scale of abscissas on the chart is on a frequency basis, 0 to 200 cycles per sec. (left to right).

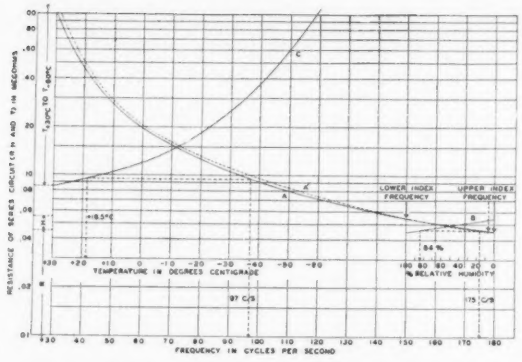

FIG. 4. Graphs illustrating the principles involved in the measurement of temperature and humidity. (A) Resistance-frequency characteristic of the modulating oscillator. (B) Resistance-humidity characteristic of the hair hygrometer. (C) Resistance-temperature characteristic of the capillary electrolytic thermometer.

For ease in interpretation, the corresponding temperature and humidity scales are also marked on the chart. The start of the run, corresponding to the release of the balloon, is at the bottom of the chart (left-hand section).

It is convenient to consider the recorder pen as producing a temperature plot which is a function of time and hence of the ascent of the balloon. This plot, represented by the vertical traces at the left of each section of the record, is not continuous, being interrupted at predetermined altitude levels of the balloon by contact of the pressure arm with the conducting strips of the switching element The modulating frequency of the emitted wave then corresponds to either the humidity or the index values. At each interruption, the recorder pen sweeps laterally to the right to record these values, returning again to the left when the pressure arm leaves the corresponding strip and the modulating frequency is again proportional to temperature. A line drawn through the frequency traces (at the right of each section of the chart) which relate to the humidity contacts will, therefore, represent the variation of humidity as the balloon ascends. Similarly, vertical lines through the two sets of index frequency traces represent the 0 and 100 percent points of the scale of humidity values. The horizontal traces of the record made by the recorder pen in sweeping from the temperature traces to the humidity (and index) traces, and *vice versa*, show that the pressure arm has reached definite points of deflection and may be evaluated in terms of pressure, based on previous calibration. Note that the humidity readings occur in groups of four while the index traces define the 5th, 10th, 15th, 20th, etc., contacts. On the record, the values of the barometric pressure corresponding to the beginning of contact of the pressure arm with the index conducting strips are shown. The balloon altitude at these points, corrected for the indicated temperature and humidity, are also shown. Similar data are not inserted for the other contacts for the sake of clarity of the record.

III. IMPROVEMENTS OF THE SYSTEM

On the basis of the foregoing brief description, an analysis can be made of the factors which determine the accuracy of measurement of pressure, temperature, and humidity. The pressure measurements, being on an absolute basis, may be carried out as accurately as the design of the pressure diaphragm and linkage will permit. The accuracy of the temperature and humidity observations, being made in terms of measurements of the modulating frequency, depend upon (1) the stability of the modulating oscillator and (2) the method followed in making the frequency measurements.

1. Transmitter Redesign

The factors involved in the measurement of temperature and humidity may be understood by reference to Fig. 4. In this illustration, graph A represents a plot of the variation in frequency of the modulating oscillator as a function of the total resistance of the series circuit (R, H, and T) of Fig. 1. In the standard circuit adopted, R has a value of 45,000 ohms, H a value of 10,000 ohms, and T a value ranging from approximately 30,000 ohms at $+30°$C. to approximately 1,025,000 ohms at $-60°$C. The respective resistance ranges are clearly indicated on the ordinate scale of Fig. 4. The two index frequencies corresponding to the circuit conditions when the pressure arm leaves in the circuit, the resistors R and H in series, or R alone, are, respectively, 150 and 180 cycles per sec. and coincide with the 0 and 100 percent relative humidity values.

Graph B of Fig. 4 shows the variation of the humidity resistor as a function of relative humidity. The corresponding variation of the modulating frequency with relative humidity may be determined from graph B used in conjunction with graph A. In the example, shown by the dotted lines, a relative humidity of 84 percent corresponds to a modulating frequency of 175 cycles per sec. Consider now the effect on the accuracy of the humidity indications of frequency drift in the modulating oscillator, or of a shift in its resistance-frequency characteristic as illustrated by the graph A' in Fig. 4. In the former case, the two index frequencies change on a proportionate basis, the ratio of the two frequencies remaining unchanged. In the latter case, the change in the two index frequencies is not proportional. In either case, however, since the average curvature of the portion of graph A or A' between the two index frequencies remains approximately the same, the relative humidity corresponding to a given indicated frequency may be accurately determined from its relationship to the two index frequencies.

Graph C of Fig. 4 shows the variation in the resistance of the electrolytic thermometer as a function of temperature. The variation of the modulating frequency with temperature may be evaluated from graphs A and C. In the example shown, an ambient temperature of $+18.5°$C. would be indicated by a modulating frequency of 97 cycles per sec. provided that the lower

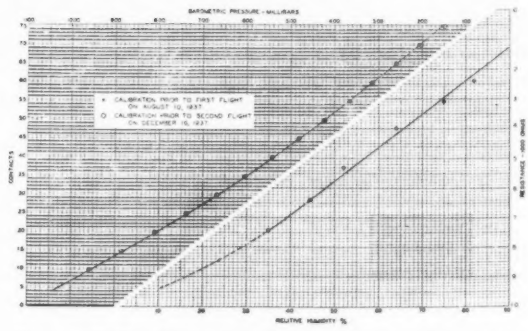

FIG. 5. Calibration curves of the barometric-pressure unit and of the hair hygrometer.

index frequency remained at 150 cycles. If, due to varying battery voltages in the transmitter, the lower index frequency should read, say, 5 percent higher, (157.5 cycles), it would be expected that the temperature reading would also be 5 percent higher (101.9 cycles). Thus the lower index frequency may be used as a control point for correcting the indicated temperature readings from frequency drift in the transmitter. This correction is, however, based on the assumption that the amount of frequency drift is proportional to the frequency, *i.e.*, that the law of variation of frequency with resistance for the modulating oscillator is independent of the battery voltages.

In the first tests of the system, it was observed that two factors operated to modify the resistance-frequency characteristic as the battery voltages changed. The first was the change in internal resistance of the plate battery with discharge, accelerated by the very low ambient temperatures. The second was the change in the bias on the control grid of the modulating oscillator caused by variations in the stray radio-frequency voltages fed back to the control grid. The net result of a shift in the resistance-frequency characteristic appears as a tilting of the graph A about the 150-cycle point (to a position such as represented by graph A'), once the correction on a proportional basis to a lower index frequency of 150 cycles is made. For this graph an indicated frequency of 97 cycles would correspond to a true temperature of $+15°$C. rather than to an indicated temperature of $+18.5°$ as determined from graph A. Hence an error of 3.5 degrees was introduced by the procedure of applying correction for drift in terms of the lower index frequency on a proportional basis.

Shifting of the resistance-frequency characteristic was reduced to a negligible amount by a few minor changes in the circuit arrangement of the radio meteorograph transmitter. A small neon-type voltage-regulating tube was added across the plate supply to the modulating oscillator which operates to take the internal battery resistance out of the frequency determining circuits. Also, through the use of a balanced, inductively coupled, transmitting antenna, and through suitable shielding and bypassing of the carrier-frequency circuits, the feed-back of radio-frequency voltages to the control grid circuit of the modulating oscillator was reduced to a minimum.

2. *Receiver Redesign*

To achieve maximum accuracy of temperature and humidity observations, improvements were incorporated in the frequency-indicating and recording system at the ground receiving station. First, because of the relatively small portion of the frequency scale covered by the humidity readings, a new recorder was adopted having a much wider scale. While this does not give an increase of the absolute accuracy, the increased ease of reading the record results in an effective increase of accuracy. Secondly, to facilitate the procedure of using the lower index frequency as a control point, an adjusting resistor was added to the electronic frequency meter for expanding or contracting its scale of frequency indication, as desired. The importance of this control during calibration and in actual operation will appear from the following sections.

3. *Simplification of the Calibrating Procedure*

The procedure for calibrating the complete radio meteorograph as described in reference (1) has been simplified somewhat. The pressure unit is calibrated by subjecting it to a varying pressure and noting the values corresponding to which the pressure arm just contacts the conducting strips. Readings are now taken only at the index contacts. A special graph paper, see Fig. 5, in which the ordinates are spaced proportionally to the spacing of the conducting strips in the switching element, permits ready interpolation for the pressure values corresponding to the humidity contacts. The effect of ambient temperature on the pressure readings is taken into account as follows: The correction per degree Centrigrade is determined at standard barometric pressure. Because of the complete evacuation of the diaphragm, this correction factor tapers off to zero as the lower limit of the pressure scale is approached. The actual temperature correction is applied on the basis of this factor, the observed pressure and temperature readings, and the estimated temperature lag of the pressure diaphragm.

The remaining measuring elements, consisting of the capillary thermometer and of the hair hygrometer are calibrated in terms of resistance. The graphs of Fig. 4 showed how these resistance values are interpreted in terms of the resistance-frequency characteristic of the modulating oscillator. The latter characteristic is determined by inserting successively in the grid circuit of the modulating oscillator (in place of the temperature tube), a series of standard resistors and noting the corresponding frequency indications on the electronic frequency meter. For zero value of the inserted resist-

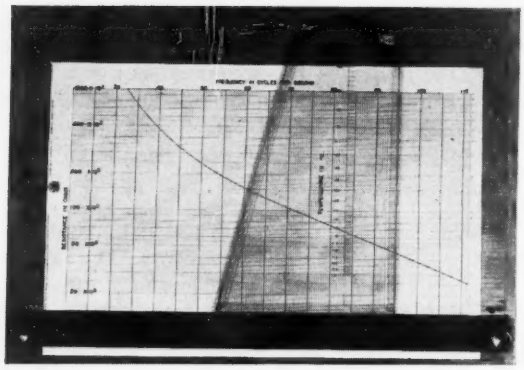

FIG. 6. Illustrating the method of correlating the resistance-frequency characteristic of a given transmitter with the resistance-temperature characteristic of a given temperature tube.

ance, corresponding to the lower index frequency, the frequency meter is adjusted to read 150 cycles. The values of resistance and corresponding frequencies are then plotted on semi-logarithmic paper as shown in Fig. 6. Only the portion of the characteristic used in the measurement of temperature is normally plotted, since the humidity values can be evaluated directly from the record by means of a simple scale.

For a given temperature tube, the ordinate scale of Fig. 6 may also be marked in terms of temperature. However, in practice, a scale engraved on celluloid or photographically printed on glass for converting the ordinate scale into corresponding temperature readings is used. The utility of this scale will appear from the following considerations. To reduce the requirements as to the accuracy of the bore in the manufacture of the temperature tubes, the resistance of a given tube, say at +30°C. may fall within the range of from 27,000 to 33,000 ohms. Since all tubes are filled with a standard electrolyte, the law of variation of resistance with temperature will remain fixed. Hence, plots on semi-logarithmic paper of several tubes having different values of initial resistance would give a series of graphs (similar to graph *C*, Fig. 4), which are parallel to each other. A sliding ordinate scale could be adapted to make these graphs coincide. Our special scale performs this operation. In the example shown in Fig. 6, the resistance of the temperature tube is 29,000 ohms at +30°C. The position of the celluloid scale is therefore fixed on the graph paper by means of the T-square so that +30 on the scale coincides with the 29,000 ohm resistance ordinate of the paper. Then if the vertical line on the scale is made to concide with a given frequency, the intersection of the graph with the scale will show the corresponding temperature for the particular tube used.

4. *Reduction of Required Tolerances*

The calibrating procedure just outlined affords several important advantages. (1) It permits the calibration of the component units of the radio meteorograph independently of each other and allows their combination without special regard to the matching of given units. (2) The tolerance permitted in the adjustment of the audio oscillator is quite broad. (3) The electronic frequency meter need not measure accurately the true values of the modulating frequency. (4) The calibration of an individual temperature tube is required only at a single temperature (say, at +30°C.), provided that a scale of the type shown in Fig. 6 has previously been prepared to match the resistance-temperature characteristic of the standard electrolyte used.

The advantages outlined under (2) and (3) require further explanation. Assume that the lower index or control frequency for a given transmitter is actually 143 cycles. During calibration the scale of the electronic-frequency meter is adjusted to make the indicated value read 150 cycles. The resistance-frequency characteristic of the modulating oscillator is then determined. Inaccuracies in the scale of the frequency meter are automatically compensated in this calibration. The frequency meter merely gives indications which bear definite relations to the standard resistors inserted in the grid circuit of the modulating oscillator. During a given ascent, as the lower index frequencies are received, they may differ by a few cycles from the value of 150 cycles, due to changing battery conditions, etc. It is only necessary to adjust the frequency-meter scale at each lower index reading so that the indicated frequency is exactly 150 cycles. Then, automatically, the indicated frequency readings corresponding to temperature and humidity observations become resistance readings and are interpreted in terms of resistance as explained. The need for close tolerance of the modulating oscillator and for absolute accuracy of the frequency-meter indications is thus obviated.

IV. SIMULTANEOUS RADIO METEOROGRAPH AND AEROGRAPH ASCENT

To determine the performance of the radio meteorograph under typical service conditions, a series of 50 early morning ascents were made in cooperation with the aerological and radio personnel at the Naval Air Station, Anacostia, D. C. The observations obtained from each ascent were checked against simultaneous observations secured in the regular early morning Navy aerograph ascents. The observation of pressure, temperature, and humidity readings obtained at the ground receiving station for each ascent were plotted on the standard adiabatic chart with temperatures and humidity as absciassas and pressures as ordinates. The significant points taken from the corresponding aerograph records were then plotted on the same chart for comparison.

A typical plot, corresponding to the radio meteorograph record shown in Fig. 3, is given in Fig. 7. In this plot, only the lines on the adiabatic chart essential to

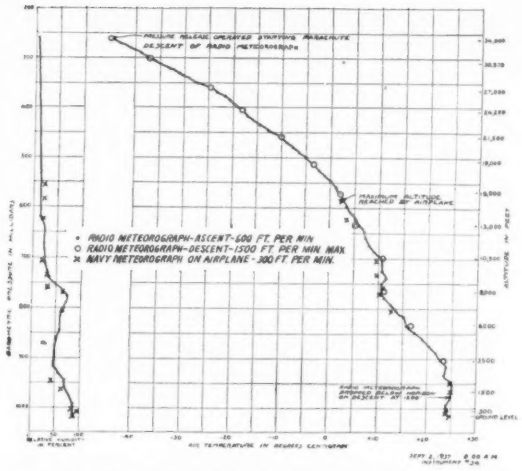
PRESSURE MILLIBARS OPERATED STRATOSPHERE PARACHUTE
DESCENT OF RADIO METEOROGRAPH
MAXIMUM ALTITUDE REACHED BY AIRPLANE
RADIO METEOROGRAPH-ASCENT-600 FT. PER MIN.
RADIO METEOROGRAPH-DESCENT-1500 FT. PER MIN. MAX.
NAVY METEOROGRAPH ON AIRPLANE - 300 FT. PER MIN.
GROUND LEVEL

FIG. 7. Comparison of the observations corresponding to the radio meteorograph record of Fig. 3 with simultaneous observations secured by an aerograph sounding.

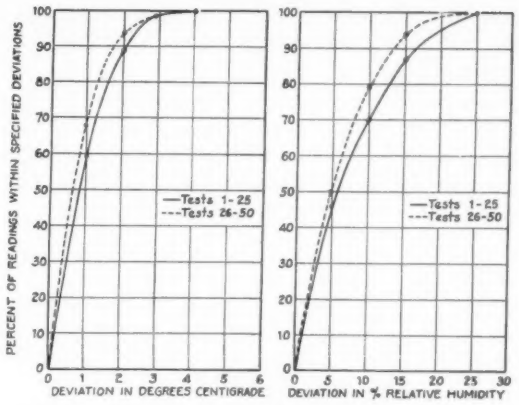

FIG. 8. Graphs showing the percentages of the radio meteorograph observations falling within specified deviations from the corresponding aerograph data.

the comparison are reproduced and the ordinate scale is slightly modified. The full lines represent the radio meteorograph data during the ascent, the circles correspond to the radio meteorograph data during the descent, and the crosses show the simultaneous aerograph observations. The humidity readings corresponding to the descent of the radio meteorograph are not plotted since these readings, while indicating changes at the proper altitude levels, did not check the ascending values because of the inherent lag in the hairs after exposure to low temperatures. The close agreement of the three sets of temperature readings testify not only to the accuracy of the temperature measurements with the radio meteorograph but also to the accuracy of the pressure measurements. The rapidity of the response of the electrolytic thermometer is also indicated since, during the descent, its rate of motion through the air was approximately double the rate for the ascent and still the same readings were obtained.

A summary of the comparisons of the data for the 50 simultaneous radio meteorograph and aerograph ascents may best be shown by means of the graphs of Fig. 8. The data for these graphs were obtained as follows. For each comparison test, the deviations of the radio meterorograph temperature and humidity readings from the significant points taken from the aerograph chart were determined. The data were tabulated in two sets of 25 tests each. The reason for this division was to determine the improvement in performance arising from a number of minor refinements in circuit arrangement and in operating procedure. The full lines in Fig. 8 refer to the first set of tests and the dotted lines to the second set.

The graphs of Fig. 8 represent the total percentages of the radio-meteorograph readings falling within specified deviations from the aerograph readings. For the second set of tests, it will be seen that 94 percent of the temperature readings agreed with the aerograph readings within 2°C. and 79 percent of the humidity readings agreed with the aerograph observations within 10 percent relative humidity.

A further breakdown of the data plotted in Fig. 8 is of interest. For the second set of tests, 68 percent of the temperature readings deviated by 1°C. or less from the aerograph readings, 26 percent by from 1° to 2°, 5 percent by from 2° to 3°, and 1 percent by from 3° to 4°. Similarly, 51 percent of the humidity readings deviated by 5 percent relative humidity or less from the aerograph readings, 28 percent by from 5 to 10 percent relative humidity, 15 percent by from 10 to 15 percent relative humidity, and 5 percent by from 15 to 20 percent relative humidity. It will be seen that a majority of the readings agreed within 1°C. and 5 percent relative humidity. When it is considered that a check of 1°C. in temperature and 5 percent in relative humidity between two separate aerograph instruments is considered acceptable in most laboratory practice, this set of data demonstrates rather definitely that the radio meteorograph is ready for practical application.

In the graphs of Fig. 8 some account was taken of the possibility that the radio meteorograph and aerograph may travel in substantially different portions of an air mass by making a conservative adjustment of the readings corresponding to the most pronounced inversion points. This adjustment consisted of assuming that the radio meteorograph and aerograph readings corresponding to these inversion points occurred at the same pressure levels; no changes were made in the actual values of the temperature and humidity readings. In all, some 5 percent of the readings were thus adjusted. It is of interest to present the results of the comparisons without making these adjustments. Under these conditions, for the second set of tests, 87 percent of the temperature readings agreed with the aerograph observations within 2° C. and 77 percent of the humidity readings agreed within 10 percent relative humidity.

The possibility that the radio meteorograph and aerograph may take soundings of somewhat different air masses points to the probability that the radio meteorograph observations were actually more accurate than the comparison tests showed. To demonstrate this probability, a series of six comparison tests were made in which simultaneous observations from radio meteorographs and meteorographs carried on the same balloon were sought. Both sets of data were in turn to be compared with simultaneous aerograph observations. The three meteorographs recovered showed much closer agreement with the radio meteorograph observations than with the corresponding aerograph readings.

Letter to the Editor

Aug. 13, 1938

Dear Sir:

A few years ago a number of articles on wind-tunnel representation of the ground appeared in the Journal. When using a ground plate it is customary to set the model well aft of the plate leading edge to prevent flow around this leading edge, which would not only result in a warped flow past the model but would also reduce the velocity at the model. This distance however results in a not inappreciable boundary layer beneath the model, and it is this boundary layer which has caused a large part of the criticisms made of tunnel tests on ground vehicles (Fig. 1). With the duplicate-model method, it is obviously possible to have an undulating flow and turbulent interchange between the models and most particularly between the two wakes, thus simulating a flapping flag more closely than a flat ground; flow pattern photographs have borne this out.

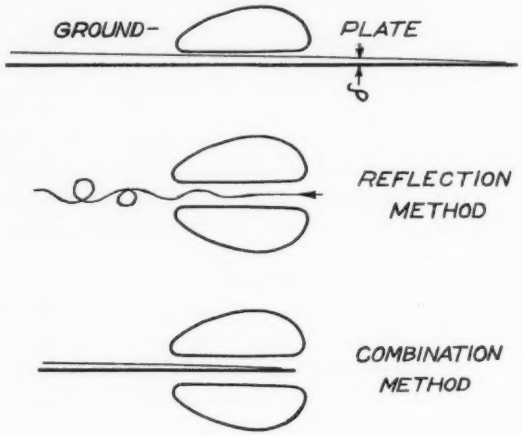

FIG. 1.

If, however, we place a model close to the leading edge of a plate, thus avoiding excessive boundary layer depth, and then prevent the usual warping of the flow by placing a duplicate model underneath, we have gotten around the bad points of both methods. It seems logical to term this the combination method. Fig. 2 shows this type of setup in the Kansas University tunnel. As a final step in balancing the flow a flap or flaps at the trailing edge of the plate may be reset until wool tufts or the like show that the flow strikes the leading edge parallel to the plate itself. The use of flaps will cut down the accuracy needed in the construction of the dummy model, and will correct for the asymmetry of flow which the balance fairings will tend to cause.

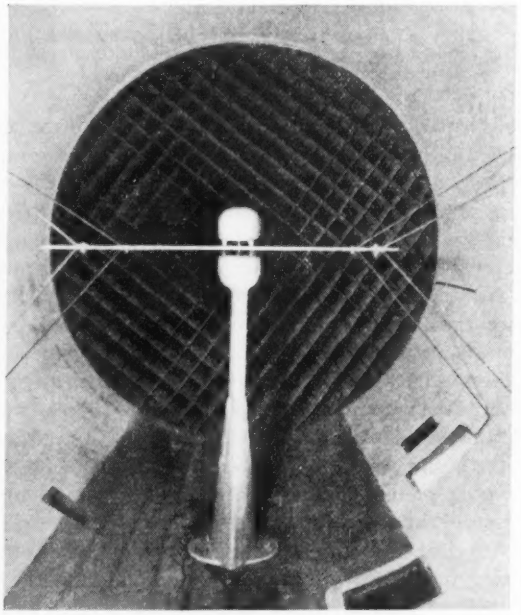

FIG. 2.

The use of a moving belt is very difficult to put into practice, and as put into practice is not correct theoretically for two reasons, both resulting from the space occupied by the setup. First there is the velocity gradient next to the belt, and extending past the model, caused by the compressing of the streamlines past the apparatus; and second there is the boundary layer which is built up as the air comes around the nose fairing of the apparatus.

It is necessary to choose methods which cause the smallest percentage error at the most reasonable cost. The combination method would appear to do this for many types of test; its effectiveness is ruined, of course, where a long model must be used, and for rough tests the item of expense makes the simple ground plate preferable.

Time permitting, a series of tests will be made at the University of Kansas comparing the results obtained by the ground plate, duplicate-model, and combination methods, covering a variety of conditions, *e.g.*, various lengths of plate.

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University of Kansas

Estimation of Wing Weights

JAMES E. LIPP, *Douglas Aircraft Company*

(Received June 27, 1938)

ABSTRACT

A method for making preliminary estimates of wing weights is described. Equations are given to show the manner in which spar cap, spar web, rib, and miscellaneous weights vary with the dimensions of the airplane.

FOR purposes of making preliminary weight estimates it is desirable to know the manner in which wing weight depends upon the size and shape of an airplane. Such knowledge can also be of use in determining a wing that will give the best compromise between structural lightness and performance for any given case. In this present report is described an approximate method that has been used at the Douglas Company for estimating wing weights and also for studying the trend of wing weights for large airplanes.

Notation:

u	=	total wing structural weight
$u_1 \ldots u_n$	=	component parts of u
τ	=	"effective thickness" of skin
ρ	=	density of dural lbs. per cu. in.
x	=	distance of station from tip
A_1	=	cross-sectional area of "bending material" at x
b	=	span
c	=	chord
S_c	=	design stress in spar cap material
S_s	=	design stress in shear webs
S_c'	=	design compression stress in ribs
M	=	bending moment at x
e	=	distance of extreme fiber from neutral axis of section
I	=	moment of inertia of section about its neutral axis
$k_1 \ldots k_3$	=	dimensionless constants
$K_1 \ldots K_3$	=	coefficients having dimensions of lbs. per cu. in.
t	=	thickness of wing at x
f	=	design load factor
w_x	=	running lift load (lbs. per in.)
W	=	gross weight of airplane
W_1	=	W minus u
W_2	=	non-structural dead weight in wing
m	=	root thickness/tip thickness
n	=	root chord/tip chord

Subscript R refers to root of wing

Subscript refers T to tip.

Two types of loading must be considered, (1) aerodynamic and (2) dead loads. These can be handled separately and the results can be superimposed in order to calculate the net effect of the loads on the wing. Three component parts of the wing structure act more or less independently and are assumed to be independent: they are (a) spar cap material (wing bending), (b) spar webs (shear), and (c) ribs (crushing loads).

1. *Aerodynamic Loads*

(a) *Spar cap material needed to resist lift forces*

Suppose the stiffeners and spar cap material are spaced uniformly around the wing section. Then the skin, spar caps, and stiffeners are replaced by an "effective thickness" τ of skin which will carry the same bending moment at the same stress. The weight of bending material in half the wing is:

$$u_1 = \rho \int_0^{b/2} A_1 dx \tag{1}$$

Assume the perimeter of the wing section to be proportional to chord.

$$A_1 = k_1 \tau c$$

We know from experiments that for most wings the stress in the spar cap material is closely approximated by the beam formula

$$S_c = Me/I \tag{2}$$

where

$$e = k_2 t \tag{3}$$

$$I = k_3 t^2 \tau c \tag{4}$$

In order to find M, let the air load be distributed along the span in proportion to the chord. Since most wings today have straight taper, the lift distribution is assumed to be trapezoidal.

$$M = \int_0^x \int_0^x w_x dx \tag{5}$$

where

$$w_x = \frac{2Wf}{c_R + c_T}\left[c_T + \frac{2x}{b}(c_R - c_T)\right]$$

After substitution of Eqs. (2), (3), (4), and (5) into (1) and integration, the expression for u_1 is found.

$$u_1 = \frac{K_1 W b^2 f m}{S_c t_R (n+1)(m-1)^3}\left\{\left[\frac{3}{2} - 2m + \frac{m^2}{2} + \log m\right] + \frac{(n-1)}{3(m-1)}\left[-\frac{11}{6} + 3m - \frac{3m^2}{2} + \frac{m^3}{3} - \log m\right]\right\} \quad \text{(I)}$$

This equation was developed in a different form by Gouge of Short Brothers.[1] Inasmuch as his derivation was based upon slightly different assumptions than those above, it is believed that most of the errors introduced by the assumptions are absorbed in the coefficient K_1.

Formulas for other weight items can be obtained in a similar manner by integration along the span, and are given below without derivation.

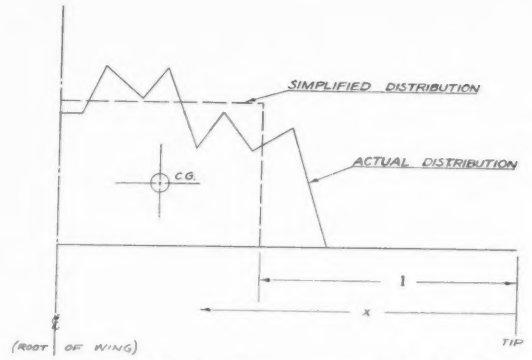


FIG. 1. Distribution of non-structural dead loads.

(*b*) *Spar web material necessary to resist lift forces*

$$u_2 = K_2 W b (n+2) f / S_s (n+1) \quad \text{(II)}$$

(*c*) *Rib material*

$$u_3 = K_3 W f t_R (m+1) / S_c' 2m \quad \text{(III)}$$

2. Dead Loads

Dead weights in the wing can be placed into two groups according to their structural or non-structural natures. The first of these groups, structure, is distributed along the span in roughly the same manner as the aerodynamic load. It can most easily be included in the calculations by substituting

$$W_1 = W - u \text{ (estimated)} \quad (6)$$

into Eqs. (I) and (II).

This substitution would seem at first glance to introduce an element of trial and error into the problem, since u (estimated) is unknown. It should be noticed, however, that u is small compared with W (less than 15 percent) so that a reasonable error in guessing the value of u will result in a very small error in the final answer.

Non-structural items, such as engines, fuel, etc., are largely concentrated near the root of the wing. Assume these weights to be distributed along the span as a rectangle having the same c.g. location and the same total magnitude as the actual dead weight, Fig. 1.

(*a*) *Effect of dead load bending*

$$u_4 = -\frac{K_1 W_2 f b^2 m}{2 S_c t_R (m-1)^3}\left\{-(m-1)(1+rm-r) + \frac{(1-r)}{2}(m-1)^2 + \frac{(1+rm-r)^2}{1-r}\log\left(\frac{m}{1+rm-r}\right)\right\} \quad \text{(IV)}$$

where $r = 2l/b$ = ratio of unloaded tip length to semi-span.

(*b*) *Effect of dead load shear*

$$u_5 = -\frac{1.5 K_2 W_2 f b (1-r)}{S_s} \quad \text{(V)}$$

Note that K_1 and K_2 are the same in Eqs. (IV) and (V) as in Eqs. (I) and (II). Since dead loads are opposed to lift forces, the dead-load terms are given minus signs. Effects of dead-load (inertia) forces upon rib weights are neglected.

The net weight of the structure as it has been considered this far is:

$$u = u_1 + u_2 + u_3 + u_4 + u_5 \quad (7)$$

Inspection of the equations shows that they are all of the form

$$u_n = K W f b (b/t_R)^q \phi_n / S \quad (8)$$

where ϕ_n is the dimensionless function of shape for each component, u_n. The exponent q has the following meaning:

$q = 1$, spar cap material
$q = 0$, spar web material
$q = -1$, rib material

The quantities b/t_R and ϕ_n are both dimensionless, so that if it is assumed for the moment that W_2/W, W_1/W, b/t_R and S_c, S_s, and S_c' are constant for all airplanes then the equations reduce to:

$$u/Wf = Kb \quad (9)$$

This means that a plot of u/Wf vs. b should be a straight line for exactly similar airplanes of different sizes.

A number of actual modern wings have been plotted in this manner and all lie near the line shown in Fig. 2. This empirical line does not pass through the origin, indicating that a portion of the wing weight is independent of span and giving rise to a sixth component of u.

$$u_6 = .0075 Wf \quad \text{(VI)}$$

[1] Gouge, A., *Flying Boats*. Report of lecture delivered before the North East Coast Institute of Engineers and Shipbuilders. England, March, 1935.

Application

Practical use of the formulas involves taking a known airplane as a reference in order to calculate the wing weight of a new airplane. The process can best be described as a series of steps.

(A) Old wing

(1) From Eq. (VI) find u_6 and subtract from wing weight.

(2) Divide the remainder into spar caps, webs, and ribs in proportion to the actual weights of these items.

(3) Noting that

$u_1 + u_4$ = spar caps (and stringers)
$u_2 + u_5$ = spar webs
u_3 = ribs

calculate K_1, K_2, and K_3. Use W_1 in place of W in Eqs. (I) and (II).

(B) New wing

(4) Estimate u from Fig. 2 and subtract from W to find W_1.

(5) With W, W_1, dimensions of the wing, and K_1, K_2, K_3 above, find the bending, shear, and rib weights.

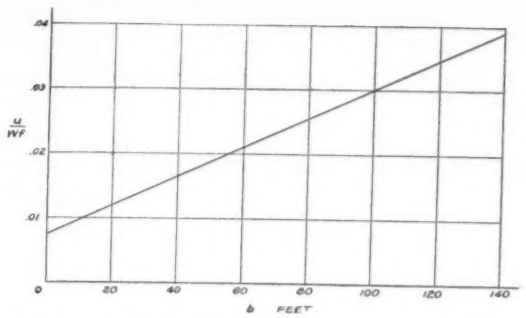


Fig. 2. Variation of wing weight with size of airplane.

(6) Calculate u_6 and add to the items in step 5 to find the total wing weight.

In closing, there are two points that deserve mention. First, the quantities $\phi_1 \ldots \phi_5$ can be plotted against m, n, and r, within a reasonable range of values in order to simplify calculations. Second, the curve of Fig. 2 cannot remain a straight line indefinitely, because large airplanes are not geometrically similar to small ones. The eventual shape of the curve will depend upon future design trends for giant planes.

Book Review

Handbook of Aeronautics, Vol. III, published under the authority of the Royal Aeronautical Society; Sir Isaac Pitman & Sons, London, 1938; 250 pages, 162 figures, $6.00.

The book is divided into three parts, *viz.*; Part I, *Aircraft Design Data and Formulae*, by Captain J. Lawrence Pritchard; Part II, *Airscrews*, by C. N. H. Lock; Part III, *General Tables and Conversion Factors*.

A better title for Part I would be Stress Analysis Data and Formulae rather than design since Captain Pritchard has dealt almost exclusively with the methods and formulae of structural analysis—and perhaps rightly so as no compact book could cover both analysis and design proper. The first query in regard to such a text is how far it applies to American practice. Naturally Section 1, "General Conditions for Ascertaining the Strength of Aircraft" derives from the rules set up by the British Air Ministry and differs from our own rules. But apart from this difference in setting up load conditions (and it is always interesting to compare load conditions) the Handbook is pleasingly international in character. Thus for load distribution between wings, reference is to reports of the N.A.C.A. but for leading edge slots British sources are drawn upon appropriately. The few pages devoted to the stress problems of seaplane are well written, though we wish that some writer would deal more exhaustively with this topic. Section II, Beam Formulae might have been written on either side of the Atlantic even if references are more generally British and contains all the necessary formulae on spars in combined bending and compression, etc. Thin Metal Construction and Stressed Skin Formulae are covered, but perhaps too briefly for American requirements. On the other hand Section III on Struts and Tubes contains everything the heart of the stress analyst requires, whether in considering compression, torsion, or combined loads. Miscellaneous Formulae are fairly complete and the Bibliography is excellent and exceptionally comprehensive. Formulae and diagrams are all clear and well connected, the work is practical yet scholarly, concise yet immediately intelligible. Probably an experienced American stress analyst has the information presented available somewhere in his library, and probably he has fuller information available in some respects, yet he would be well advised to add the Handbook to his working library, saving time and mental wear and tear and deriving benefit from another point of view. Part II dealing with Airscrews is both businesslike and thorough and Mr. Lock has not been afraid to take the most advanced theories of the propeller and reduce them to design room requirements. Many useful charts are given. A specialist in propeller design would seek a more comprehensive guide; the aeronautical engineer in general would probably find all he is likely to need. In Part III, General Tables and Conversion Factors, the user of the Handbook will be pleasantly surprised that he can readily find just the miscellaneous information that he requires so frequently and on which he may waste so much valuable time. It is handy to find power corrections for altitude, gage numbers, common integrals, and the weight of a gallon of sea-water all in a few pages. The compiler must have suffered long himself to select and present just the right sort of material.

Alexander Klemin
New York University

Some Aerodynamic Problems in the Design of the Convertible Airplane

GERARD P. HERRICK, *Herrick Vertaplane Corporation*

Presented at the Rotary Wing and Lighter-Than-Air Aircraft Session, Sixth Annual Meeting, I. Ae. S. January 25, 1938

ABSTRACT

The main feature of this paper lies in the fact that, up to July 30, 1937, heavier-than-air machines could be divided into two general classes. In the first class were the *airplanes* with their refinements and improvements for efficiency and speed. In the second class were the *rotor-planes* with their special characteristics of jump-off, hovering, high-angle and vertical take-off, and landing.

On July 30, 1937, a convertible airplane took off and landed as an airplane, did likewise as a rotor-plane, and then took off and flew as an airplane or machine of the first class mentioned, and, at 1700 ft. released and started its upper wing in rotation, landing as a rotor-plane, or machine of the second class mentioned. This might be regarded as demonstrating a new class, the *convertible*, a combination of both airplane and rotor-plane.

Conversion of the *convertaplane* was accomplished by releasing and starting the upper wing rotating and by control of its unbalanced moments, occasioned by the differential in lift between the advancing and receding blades of the rotor-wing.

THE CONVERTIBLE AIRPLANE

THE treatment of the aerodynamic problems in this paper will specifically refer to the vertaplane, which will hereafter be called the convertaplane, shown as a biplane. (See Type HV-2A, Fig. 1.)

Passing over the engineering problems of obtaining stability for the change of center of lift when the convertaplane converts from a biplane to a gyro, the method of release, the reaction upon the ship of starting rotation, etc., there is the problem of a series of aerodynamic changes taking place while the rotor-wing is accelerating from its fixed position as a wing to normal speed of rotation as a rotor.

When the present efficient arrangement, of using the identical wing structure as a wing and as a rotor, had been tentatively chosen, these unsolved aerodynamic problems took definite form. For example, in conversion, there are two outstanding aerodynamic conditions involved when changing from a fixed wing to a spinning rotor: (I) when the rotor-wing starts rotation, and (II) when the lift-differential between the advancing and receding blades of the rotor-wing reaches its maximum.

BASIC PRINCIPLE OF AUTOROTATION

For purposes of clarity, especially for those who have not had occasion to go into the phenomenon of autorotation, some fundamental conditions at two instants

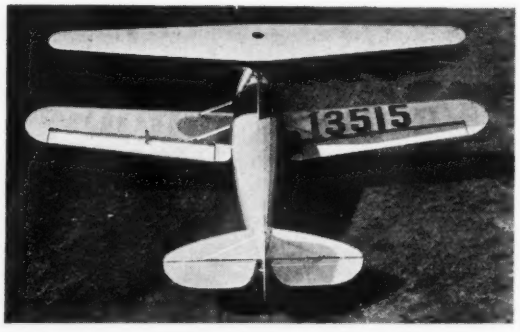


FIG. 1. The Convertaplane, Model HV-2A.

and two points are worth mentioning. The basic ideas will be restricted to a non-oscillating, non-feathering, two-blade rigid rotor of the fore and aft symmetrical type.

Considering the rotor as stationary and oriented across the wind and neglecting interference, the ordinary simple conditions of lift and drag would be as follows in Figs. 2, 3, and 4.

In Fig. 2 assume the wind as shown, and the line XY as the chord of the rotor-wing profile at points P and P' (Figs. 3 and 4) and P its center of pressure. Then the lift and drag may be represented by lines PA and PA', respectively, resulting in PB.

Then PB analyzes into components PC perpendicular to chord XY and PC' as a windward component in the plane of the chord.

In Figs. 3 and 4 points P and P' are assumed to be the center of pressure of each blade of the rotor-wing and correspond to point P on the profile. (See Fig. 2.)

The rotor being stationary, relative to axis Z, and across wind, as in Fig. 3, the windward components PC' and $P'C'$, being equal and on opposite sides of rotor axis Z, balance each other. However, when the rotor starts to rotate as shown about axis Z, then $P'C'$ becomes greater on the advancing blade than PC' on the receding blade, which in fact, at certain points, reverses into drag PA' and there is a tendency to rotate in the direction indicated.

It is true that for this discussion these conditions have been simplified and that no such case actually exists in all its details, but the general principles to be

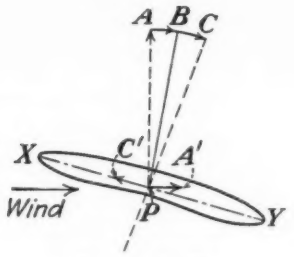
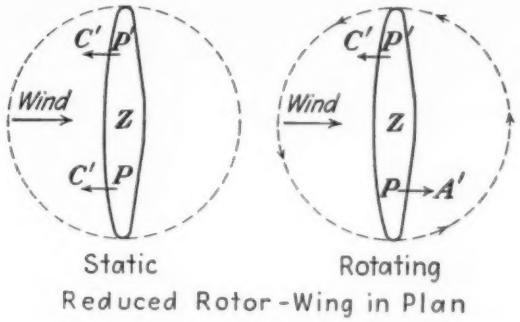


FIG. 2. Profile.



FIGS. 3 and 4. Reduced rotor-wing in plan.

considered are truly illustrated, which is all that is necessary for the scope of this paper.

It is the beginning of rotation, with the accompanying change of lift, etc., that creates a differential in lift and drag between the advancing and receding blades of the rotor-wing-lifting-propeller of a windmill-plane or gyro and this differential results in a rotary component of force. Again, this rotary component, when great enough and sustained up to the suitable critical speed, will cause the rotor to accelerate to the normal speed and result in continued autorotation.

The practical acceleration to the critical speed is what makes independent starting of rotation imperative. The automatic continuation happily occurs because, simply expressed, if the rotor tends to slow down it loses lift and the ship tends to fall; this increases the angle of attack and speeds up the rotor and *vice versa*. This automatic adjustment of lift and rotor speed is at the basis of autorotative flight. These are the fundamental elements of performance when starting rotation.

It is obvious that, whereas the lift was laterally balanced as a fixed wing before conversion, it is unbalanced in rotating by the difference of the squares of relative wind velocity in passing the advancing and receding blades. Also there is the stalling moment on the rotor, due to this lift as affected by rotational movement and inertia, as well as from the stalling moment of the center of lift of the rotor-wing, while it is changing from a lateral and passing through a longitudinal position.

It will be noted here that the rotor-wing in the convertaplane is not only released for rotation but also for pivotal oscillation in the vertical plane, between certain limits, so that, roughly speaking, the aerodynamically produced vertical movement in the wing is not only resisted by its own inertia but the angle of attack is reduced on the advancing blade while increasing on the receding blade, and what moment it has cannot be transmitted to the ship while, and insofar as, it is free to oscillate.

II. Maximum Lift Differential

Taking up the second condition, *viz.*, maximum lift differential, and referring to the rotor-wing as two lifting propeller blades, the maximum blade-lift differential, and, therefore, the maximum forces of conversion upon the system, will naturally occur in that region of acceleration where the center of lift on the receding blade, by reason of its rotation in the same direction as the wind, is moving in zero relative wind, while the center of lift of the advancing blade has doubled its relative wind, and roughly speaking, its lift, therefore, is quadrupled.

The effort to temporarily limit the differential lift for structural reasons, without interfering too much with the rotary component for acceleration, has been successful.

The Rotor-Wing Problem

Another interesting aerodynamic research was the rotor-wing problem. The upper wing of the biplane having to serve efficiently both as an ordinary wing and also as a rotor, involved the reversal of leading and trailing edges on half of the span and substantially equal lift for plus or minus values of V or relative wind. A study of the literature failed to reveal a wing profile possessing these essential characteristics.

In studying the flow of air around bodies, with special reference to lifting surfaces, the probable suitability of the elliptical profile was realized. The elliptical form promised the least drag for a body whose drags, in opposite directions, should be approximately equal.

However, if taken by itself, this profile offered what might be called a double cambered profile represented by the conventional equation of an ellipse in the form $y = \pm(a/c)\sqrt{c^2 - x^2}$; where y is the ordinate GF' (Fig. 5); x is the distance PG; a is one-half the maximum thickness of the ellipse or profile PM' or OM and c is one-half the chord length or PB.

In avoiding the disadvantages of the double cambered profile, the writer considered distortion of the mean camber line into an arc of a circle.

Consider the circle $X^2 + Y^2 = R^2$ such that a chord of length $2c$ lies within the circle a distance b from the circumference. The equation of the circle with reference to the centerpoint of such a chord as an origin is,

$$y' = (b^2 - c^2 + \sqrt{(b^2 + c^2)^2 - 4b^2x^2})/2b$$

Combining the ordinates of the ellipse with the cir-

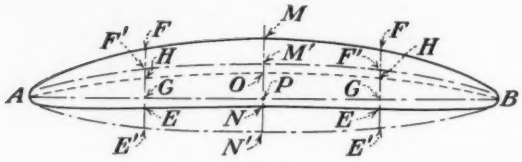
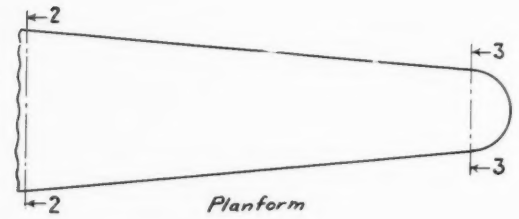
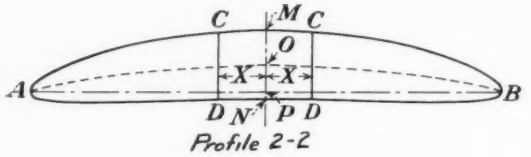


FIG. 5.





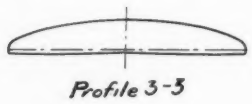


FIG. 6.

cular arc as a mean camber line, the resulting ordinates of the profile, measured at any chosen distance x from the centerpoint of the chord line, are expressed as:

$$y'' = y' \pm y = \frac{b^2 - c^2 + \sqrt{(b^2 + c^2)^2 - 4b^2x^2}}{2b} \pm (a/c)\sqrt{c^2 - x^2}$$

Fig. 5 is an explanatory diagram indicating the method of derivation of the profile. These profiles are symmetrical about the minor axis $M'N'$ of the ellipse $AM'BN'$ and about MN of the distorted ellipse $AMBN$. The mean camber is the circular arc AOB. By means of the distortion, M' assumes the position M, N' assumes the position N, etc.

Fig. 6 represents the planform and two profiles of the rotor-wing at the sections 2-2 and 3-3, respectively.

WIND-TUNNEL DATA

The characteristics of the Model data on lift, drag, and L/D of such profiles have been obtained in wind-tunnel tests at the Guggenheim School of Aeronautics, New York University. The coefficients derived from the tests of a 24-in. Model of the convertaplane rotor-wing H-12 are shown in Figs. 7 and 8.

From these facts it seems justifiable to conclude that this type of symmetrical profile can at least adequately

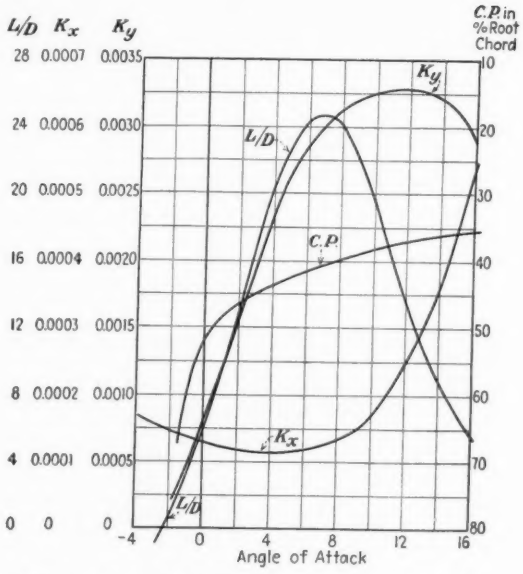


FIG. 7 Convertible Rotor-Wing, 24 in. model test as wing. N.Y.U.–W.T.T. 475N.

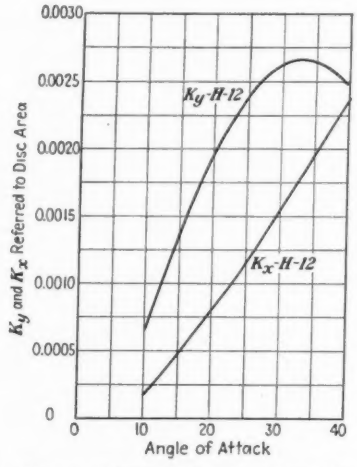


FIG. 8. Convertible Rotor-Wing 24 in. model test as rotor. N.Y.U.–W.T.T. 475N.

compete with the conventional types. Moreover, although elaborate and scientifically accurate tests of performance have not been made, nevertheless the known weight of the ship and the tested air-speed meter readings, taking into account the well-known characteristics of the lower fixed Clark Y-15 wing and the areas of the two wings, would seem to substantiate the model wind-tunnel data. The L/D of over 24, as a wing, appearing in Fig. 8 was the highest obtained.

However, the 53-in. model H-7 rotor-wing, with an L/D of over 21 (as a wing), showed a coefficient of minimum drag of 0.00006, or about $^1/_2$ of that of the H-12; the maximum lift, as a rotor, was higher and showed a disc coefficient of 0.00275.

During these tests a very interesting scale effect was indicated, namely that in passing from a 24 in. model to a 53 in. model, the minimum drag was cut in half and the raising of V from 40 to 90 m.p.h. caused an unexpectedly large improvement in characteristics. This might not have been so seriously considered, on the basis of the early data obtained, if it had not been for an investigation by the National Advisory Committee for Aeronautics.[1] Among others, tests of a series of R.A.F. profiles and a special "cylindrical segment," a symmetrical profile of the Eiffel No. 7 type, were carried out.

In speaking of these airfoil sections at very high propeller tip speeds it was concluded that "a cylindrical segment in the single test made was found to be somewhat more efficient than the airfoil sections." Notwithstanding the inherent inefficiency and weakness of this Eiffel section for wing use, these tests nevertheless seemed to indicate that, for high Reynolds Numbers, a symmetrical section might abnormally increase its L/D.

[1] Briggs, L. J., and Dryden, H. L., *Aerodynamic Characteristics of Twenty-four Airfoils at High Speeds*, N.A.C.A. Technical Report 319, 1929.

Although in the tunnel work reported here it was necessary to postpone more exhaustive investigation of this interesting effect, it did somewhat justify belief in the usefulness of a symmetrical section, especially where reversibility was desired.

The most interesting point about the profile tests was not so much the individual good characteristics as the consistency of the good results obtained from all of the H-6 to H-12 profiles made with models varying in size and workmanship under various conditions at various times and by a number of different engineers.

Reconversion, Rotor Control, Etc.

So far only conversion from plane to gyro form in the air has been discussed. It seemed wise to attack this problem first but obviously similar but reversed conversion, *viz.*, from gyro to plane as well as rotor-control, one effective form of which has been developed in the Wilford gyroplane, were considered.

Although the fundamental aerodynamic problems of the convertible airplane have been discovered and practical solutions worked out, its future usefulness now depends upon the experienced and competent specialists in the aviation industry.

Letters to the Editor

September 12, 1938

Dear Sir:

In an article recently sent the writer for review, the author applied the term "pure bending" to bending due to load placed at the elastic center of the wings. Such bending is accompanied by shear and, therefore, according to the definitions of modern textbooks should not be called "pure" bending. It would be highly desirable for structural engineers to adopt an adjective to describe bending accompanied by shear but no axial load or torsion. Since this kind of bending is characteristic of "simple beams," the writer suggests the adoption of the expression "simple bending." In the second edition of Airplane Structures he and Professor Newell have already done this, but if a better term is suggested they would be glad to change to it in future editions. If this suggestion is followed it might be desirable to limit the terms "simple bending" and "simple flexure" to cases where the load is parallel to a principal axis of the section and passes through the shear center, *i.e.*, to cases where the deflection is in the plane of the loads.

ALFRED S. NILES
Stanford University

September 18, 1938

Dear Sir:

In the paper entitled *Airfoil Theory for Non-Uniform Motion* which was published in the August issue of the Journal of the Aeronautical Sciences, the undersigned stated their belief that the representation of lift and moment by vector diagrams would be found useful in the discussion of flutter problems. In making this statement the authors overlooked the fact that such application of similar vector diagrams has already been made in an important paper by Kassner and Fingado (*Das ebene Problem der Flügelschwingung*, Luftfahrtforschung, Bd. 13, page 374, 1936; also Jour. Roy. Aero. Soc., Vol. 41, page 921, 1937). This title should be added to the list of references given in the above-mentioned paper.

In a Letter to the Editor (this Journal, Vol. 5, No. 11, page 454), Dr. Max Munk has recommended further simplification of the non-stationary airfoil theory by "altogether dispensing with the division of the forces and moments into several parts." He suggests that the only necessary appeal to dynamics is the assumption that to each vortex be ascribed a force equal to the vector product of the vortex strength and the relative velocity of the vortex. Unfortunately this simple rule cannot be extended to the case of non-stationary motion, and Munk's Eqs. (1) and (2) do not give the lift and moment correctly in the general case. The correct expression for the lift, for example, in terms of the total vortex strength distribution over the airfoil, $\gamma\ (x)$ ($= v$ in Munk's notation), is

$$L = -\rho \int_{-1}^{1} (\partial\gamma/\partial t)\, x\, dx + \rho\, U \int_{-1}^{1} \gamma\,(x)\, dx - \rho\, U \left[x\, \gamma(x) \right]_{x=1}$$

where U is the velocity of advance of the airfoil. This relation is obtained by differentiation of Eq. (12) of the paper.

The authors do not see any possibility of avoiding the division of the force and moment into various parts. They desire to take this opportunity to point out the significance of the name "apparent-mass contributions" which was applied to certain terms in their paper. In theoretical hydrodynamics this name is usually given to the forces produced by the reaction of the fluid accelerated by the motion of a solid body. To follow this definition strictly, all forces and moments which would occur without circulation should be included in this category. The authors—in accordance with common engineering practice—have included all forces and moments which may be produced by uniform translation or rotation of the airfoil in the "quasi-steady" contributions, as calculated by the usual steady-motion airfoil theory. The statement that the "apparent-mass contributions" are "the force and moment which the airfoil would encounter in a flow without circulation," which is made in the paper, page 383, should be modified accordingly. In order to avoid duplication of certain force and moment components, it is suggested that the "apparent-mass contributions" be calculated by application of the formulae derived in the paper.

TH. VON KÁRMÁN
WILLIAM R. SEARS
California Institute of Technology

Institute Notes

Honors

Ralph H. Upson, a Fellow of the Institute, and C. R. de Laubenfels, a Technical Member of the Institute, were recently awarded prizes for papers submitted to the James F. Lincoln Arc Welding Foundation. Mr. Upson's paper dealt with a type of construction and method of design permitting arc welding in an all-metal type of aircraft. Mr. de Laubenfels' paper presented the adaptation of a welded landing gear fork for an arc welded one.

Los Angeles Branch Meeting

The Fall meeting of the Los Angeles Branch of the Institute was held at the California Institute of Technology in Pasadena on September 30 and October 1, 1938. The following program was carried out.

Friday, September 30, 9 a.m.

Fluid Mechanics and Aerodynamics

Th. von Kármán, Chairman

J. Kampé de Feriet, Lille University, France, "Turbulence in Wind Tunnels."

E. F. Relf, National Physical Laboratory, England, "Aerodynamic Work at the National Physical Laboratory."

L. E. Root, Douglas Aircraft Company, "Design Aerodynamics of Single and Multiple Vertical Control Surfaces."

Friday, September 30, 2 p.m.

Flying Characteristics and Flight Testing

J. S. Marriott, Chairman

N. F. Scudder, Glenn L. Martin Company, "Flight Test Research on the Problem of Vapor Lock."

Ben O. Howard, United Air Lines, "Desirable Qualities of Transport Airplanes from Pilot's Point of View."

Saturday, October 1, 9 a.m.

Symposium on Thin Walled Structures

S. Timoshenko, Chairman

W. A. Klikoff, Civil Aeronautics Authority, "General Instability of Stiffened Cylinders."

J. R. Fischel, Lockheed Aircraft Company, "Compression Stresses and Effective Widths."

C. P. Grady, "Flat Bottom Corrugations in Combined Compression and Torsional Shear."

F. R. Shanley, Curtiss-Wright Technical Institute and Consolidated Aircraft Corporation, "Engineering Aspects of Buckling Problems."

Visitors to the Institute

The large number of foreign guests attending the International Congress for Applied Mechanics at Cambridge, Massachusetts, made it possible for the Institute to extend its hospitality to many distinguished visitors. Among these were the following: Prof.Dr. L. Prandtl of Göttingen, one of the Institute's Honorary Fellows; F. Handley Page, London, England; George E. Woods Humphrey, London, England; A. A. Griffith, Farnborough, England; Group Captain E. W. Stedman, Ottawa, Canada; R. H. Muloch, Montreal, Canada; Ernest F. Relf, Teddington, England; D. H. Williams, Teddington, England; H. C. Luttman, Stockport, England; Prof. L. Bairstow, London, England; J. H. Parkin, Ottawa, Canada; Prof. G. I. Taylor, Cambridge, England; Prof. A. J. S. Pippard, London, England; Ivor E. King, Bermuda; Air Commodore R. H. Verney. From France: Prof. J. Kampé de Feriet, Lille; Inspecteur General A. Lespresle, Paris; P. Dupont, Paris; Prof. C. F. F. Platrier, Paris; Prof. A. Metral, Paris; Philippe Deymié, Paris; H. de Leiris, Paris; Prof. Jules Drach, Paris; Jean Pontremoli, Paris; Prof. Jacques Valensi, Marseilles. From Holland: J. Th. Thysse; Prof. C. B. Biezeno, Delft. From Poland: Dr. Witold Billewicz, Warsaw; Dr. S. Fuchs, Lwow; Prof. Dr. W. Wierzbicki, Warsaw; Dr.Ing. S. Neumark, Warsaw. From Turkey: Prof.Dr. R. von Mises, Istanbul; Kerin Erin, Istanbul. From Germany: Hanna Reitsch, Prof.Dr. R. Grammel, Stuttgart; Prof.Dr. F. Koerber, Dusseldorf; Dr. Konrad Ludwig, Hannover; Prof.Dr. H. Blenk, Braunschweig; Dr. H. Lorenz, Berlin; Julius Krauss, Augsburg; Dr. K. Marguerre, Adlershof; Prof.Dr. Ludwig Schiller, Leipsig; Prof.Dr. R. Sonntag, Karlsruhe; Prof.Dr. W. Tollmien, Dresden; Dr. A. Puchen, Berlin; Prof.Dr. W. Spannhake, Karlsruhe; G. Mathias, Bremen; Prof.Dr. W. Effenbergen, Leoben; Prof.Dr. Karl Federhofer, Gratz; Prof.Dr. Karl Girkman, Wien; Dr. Ernst Weinel, Jena; H. E. Dickmann, Berlin; Robert Lusser, Augsburg; Dr. W. Barth, Friedrichshafen; Prof.Dr. H. Schlichting, Braunschweig; Dr. F. Schultz-Grunow, Göttingen. From Japan: Prof. T. Moriya, Tokyo; Prof. Mineo Yamamoto, Tokyo; Prof. Y. Watanabe, Fukuoka.

Personnel Opportunities

The Personnel Bureau serves organizations seeking to employ aeronautical specialists as well as individual members. The Bureau has been the means of arranging several very successful connections for members.

Any member or organization may have requirements listed without charge.

Available

Graduate Aeronautical Engineer with 11 years of practical experience in the design of all-metal airplanes wishes to make a new connection. Has thorough knowledge of design, layout, and analysis of airplane structures and equipment. Previously employed in responsible positions. Familiar with many phases of Army and Navy work. Write Box 73, Institute of the Aeronautical Sciences.

Aeronautical Engineer, temporarily incapacitated, would like to obtain work translating German or French technical articles or books. Has a thorough knowledge of both languages. Write Box 74, Institute of the Aeronautical Sciences.

Necrology

Willis Ray Gregg

Willis Ray Gregg, an Honorary Member, Fellow, and member of the Advisory Board of the Institute, died on September 14, 1938, at Chicago, Illinois. He was fifty-eight years old.

Mr. Gregg had a brilliant career as a scientist and administrator. As Chief of the Weather Bureau since 1934 he greatly expanded the facilities and services of the bureau, particularly from the standpoint of air transportation. Under his direction routine upper air soundings were inaugurated early in 1934. The steady growth of this service as well as a considerable increase in the number of weather stations throughout the country, both of which facilitate much more accurate and detailed weather forecasts, are directly attributable to Mr. Gregg's efforts.

Next to his position as Chief of the Weather Bureau his most important post was that of Executive Chairman of the National Advisory Committee of Aeronautics. He had been a member of the Committee since 1934.

Mr. Gregg was born in Phoenix, New York, on January 4, 1880, the son of Willis Perry Gregg and Jennie E. Ray Gregg. He was graduated from Cornell University with an A.B. degree in 1903 and entered the Weather Bureau in 1904. He was stationed at the Mt. Weather Observatory, Virginia, from 1907 to 1914, at which time he was transferred to the Washington office. In 1917 he was appointed Chief of the Aerological Division of the bureau, which post he held until 1934 when he became Chief of the bureau. He served as special meteorological advisor for various of the early trans-oceanic flights and from 1926 to 1934 was in charge of the most modern of the bureau's activities, the development of an intensive weather service along the Federal airways system.

Mr. Gregg belonged to and played a leading part in the activities of the International Meteorological Organization, the Daniel Guggenheim Committee on Aeronautical Meteorology, and the Interdepartmental Committee on the Coordination of Meteorological Services for Aeronautics. He was a Fellow of the American Meteorological Society, a member of the Royal Meteorological Society, the American Association for the Advancement of Science, the American Geophysical Union, the Washington Academy of Sciences, the Washington Philosophical Society, and the National Aeronautic Association.

He was the author of the following books: "Trans-Atlantic Flight from the Meteorologist's Point of View" (1919); "The Wind Factor in Flight" (1923 and 1924); "An Aerological Survey of the U. S." (1922 and 1926); "Aeronautical Meteorology (1925, rev. ed. 1930).

Mr. Gregg's name stands high among those responsible for the degree of development attained by Aeronautics up to the present time, and, in addition, his work as Chief of the Weather Bureau helped to lay a substantial foundation for future development. He is survived by his wife, Mrs. Mary Wall Gregg, and by his daughter, Miss Ruth Marguerite Gregg.

Oscar Westover

Major General Oscar Westover, an Honorary Member and member of the Advisory Board of the Institute, was killed in an airplane accident on September 21, 1938, at Burbank, California. He was fifty-five years old.

General Westover, Chief of the Army Air Corps, had been for the past seven years a commanding figure in the Army Air Service, of which he had been head since December, 1935. Largely through his efforts the Air Corps has been built up to its present high position among the world air forces.

General Westover was born at West Bay City, Michigan, July 23, 1883, and was a West Point graduate in the class of 1906. He was graduated from the General Staff School, the Air Service Airship School, the Advanced Flying School, and of the many other training units which are part of the Air Service training system.

Before entering West Point he served in the ranks as a private in the army engineering corps. As an officer his first service was in the infantry, from which he transferred to the signal corps in 1917 a short time after the United States entered the World War. In 1918 he joined the Air Service.

After the War General Westover was for some years in the lighter-than-air division of the service. He was Chief of the Airship Division from 1921 to 1922. In 1922 he won the Gordon Bennett Cup, as pilot of the winning balloon in the international balloon race.

He was assistant executive, Bureau of Aircraft Production, in 1918 and 1919, and from 1922 to 1928 was director of the army's aircraft production unit. In 1932 he was promoted to brigadier general and named assistant chief of the service.

General Westover received the Distinguished Service Medal for his wartime activities. The citation accompanying the award concluded with: "His services were of inestimable value to the government in a position of great responsibility."

General Westover is survived by his wife, Mrs. Adelaide Bainbridge Westover, a son, Second Lieutenant Charles B. Westover, of Kelly Field, Texas, and a daughter, Mrs. Patricia Westover Freudenthal of Bolling Field, Washington.

Frank Sowter Barnwell

Captain Frank Sowter Barnwell, an Associate Fellow of the Institute, was killed at Bristol Airport, England, on August 2, 1938, when an airplane he was piloting crashed.

Captain Barnwell was one of the pioneer airplane designers in the world. He designed many airplanes which have become historic. His Bristol Fighter, designed in 1916, was one of the great airplanes of the War. One of his modern designs was that of the Blenheim, a two-engined high-speed fighter, used in large quantities by the Royal Air Force.

Captain Barnwell was born in Lewisham, Kent, England on November 23, 1880. He was educated at Fettes College, and Edinburgh and Glasgow Universities. In 1906 he came to the United States to work for the Fore River Shipbuilding Company of Quincy, Massachusetts. In 1907 he returned to England and formed an engineering company with his two brothers. In 1911 he joined the Bristol and Colonial Aero Company as Chief Draughtsman. During the War, he was with the R.F.C. He was recalled from the front in order to design airplanes. Since that time he has been a designer for the Bristol Aeroplane Company.

AERONAUTICAL REVIEWS

These brief reviews of recent articles on aviation subjects are published by the Army Air Corps for the information of its officers, and are printed here each month by permission of the Chief of the Air Corps

Aircraft Design

Comparison and Graphic Representation of the Characteristics of Airplanes. J. Goldman and H. Rivière. Maximum and minimum speeds, range, ceilings and speed range can readily be obtained from the nomographs given by the first author. Points are plotted on the nomographs from published characteristics for a great many of the newer American, British, French, German, Italian and Dutch military and transport aircraft. By means of these nomographs published data on new airplanes can be compared to determine the intrinsic coefficients and whether the data are plausible. Data on airplane designs can rapidly be compared with characteristics of existing airplanes. Amiot 370 is used as an example.

Coefficients proposed by Rivière take into account the structural weight, utilizing the characteristics of the airplane and the science of sound. An original speed-characteristic coefficient is presented for the first time and is derived for the transport airplane. A second original coefficient is that for efficiency of climb. Nomographs give the speed-characteristic and climbing efficiency coefficients in function of useful load, total weight, total power, and maximum speed. L'Aéronautique, L'Aérotechnique Sup., May, 1938, pages 57–65, 7 illus., many equations.

Hall Wing Characteristics. R. F. Hall. Essential elements of the improved Hall wing consist of an automatic flap, correlated ai erons above and depressing with the flap, and a longitudinal passageway embodying a forward vane-controlled opening at the under surface near the leading edge. Development is the result of extensive research checked by flight tests on the X-90, GA21-M, F-22 Navy wing, and the GA-36 airplanes manufactured by the Cunningham-Hall Aircraft Corporation. Lift, stalled flight, take-off, steep glide and landing, and longitudinal stability and balance are described in detail. Aero Digest, August, 1938, pages 75–76, 79, 11 illus., 1 table.

An Improved Method for Calculating Free Vibrations in Systems of Several Degrees of Freedom. W. M. Dudley. New theorem makes possible a further reduction of nearly one half in the time required for calculation, so that solutions up to 20 degrees or more of freedom are now practical. It is possible to determine motion of the system after any initial disturbance in a few minutes, instead of several hours. It is useful in the latter respect whether the modes have been determined by matrix methods, or not. Paper is said to give simpler proofs than any previously published, and knowledge of the matrix theory is not required in using the method. Problems are analyzed by a tabular process, in which an ordinary computing machine helps greatly. Jour. Applied Mechanics, June, 1938, pages A61–A66, 1 illus., 36 equations.

Pilot's View in Cabin Aircraft. J. E. Serby. Principles of satisfactory windscreen design to give clear vision and wide field. General considerations applying to windscreens on all types of cabin aircraft; question of still further improving view in bad weather; side and corner openings in the windscreens; deflectors combined with front openings; windscreen for single-seater narrow-fuselage aircraft; reduction of drag of cabin tops; and prevention of draughts and rain entry through direct-vision openings. Aircraft Engg., July, 1938, pages 219–220, 4 illus.

Range vs. Payload. G. S. Schairer. Effects of airplane weight, speed, fuel load, engine r.p.m. and other factors on range. Various charts are illustrated, especially one giving a very direct method of obtaining the effect of r.p.m. on propulsive efficiency. Method of using this chart for estimating range is illustrated by a sample computation for a typical 60,000-lb four-engined land transport. Aviation, August, 1938, pages 26–27, 71, 74, 77, 9 illus., 1 table, 5 equations.

Slots and Flaps in Combination. W. M. Widgery. Combined use of slots and flaps in the design of the Westland Lysander which, in spite of a wing loading of 23 lb.–sq. ft., can fly at 55 m.p.h. Authoritative design data on the combined use of slots and flaps are given. Great improvements brought about by the use of full-span slots in conjunction with flaps are pointed out and problems solved in correct timing of the opening process, stability and trim, structure, and control are discussed. Extensive wind-tunnel work preceding the design of the flaps on the Lysander and correlation of results with those obtained in full scale are described. Specifications of the Westland Lysander included. Aeroplane, Aeronautical Engg. Sup., July 27, 1938, pages 113–116, 98 7 illus., 1 table.

The C. P. Position of Aerofoils. G. Novickis. Simple practical method for finding the approximate center-of-pressure position of an airfoil directly from the C_L (C_M) curve in cases where the c.p. positions are not indicated, as in the American and British airfoil data reports. Aircraft Engg., August, 1938, page 250, 2 illus.

Monoplane Wings with Sweep. J. R. Crean. Theoretical calculation of the spanwise lift distribution. On the basis of classical airfoil theory a system is deduced for wings with sweep which is analogous to the well-known one of Galuert for wings without sweep. Method of calculating the location of the center of pressure at any point on the wing is based on the work of H. Minski, a Russian Research worker, although the method has been modified and its scope of application extended. Aircraft Engg., August, 1938, pages 245–247, 4 illus., 2 tables, 13 equations.

Operating Characteristics of Large Flying Boats. W. K. Ebel. Paper previously abstracted from preprint. S.A.E. Jour., August, 1938, pages 7–12, 6 illus., 1 table.

Stress Analysis and Structures

Bending Stresses in Box Beams as Influenced by Shear Deformation. P. Kuhn. Paper previously abstracted from preprint. S.A.E. Jour. (Trans.), August, 1938, pages 319–324, 9 illus., 1 table.

The Continuous Beam. S. J. E. Moyes. Case of irregular lateral loading combined with end loads. Solution is based on the fact that an irregular lateral load can be considered as a number of concentrated loads with good approximation and expressions are derived whereby a solution can be effected by use of simple tabulation. Aircraft Engg., August, 1938, pages 243–244, 247, 2 illus., 28 equations.

Circular Beams Loaded Normal to the Plane of Curvature. M. B. Hogan. Expressions are derived for deflection, angle of slope, and angle of twist of the free end of a circular cantilever beam with a concentrated load acting at any point along the center line of the beam and perpendicular to its plane of curvature. Results are also given for three different cases of distributed loading. Values of reaction and angles of slope and twist at the simple support are given for a circular beam built-in at one end, simply supported at the other and loaded as in the first case. Similar expressions are presented for like beams with the same three distributed loadings as the above cantilever arcs. Equations are given for three internal reactions: bending moment, twisting moment, and shear existing at the plane of symmetry of a circular beam built-in at both ends with an arbitrarily placed concentrated load acting perpendicular to the plane of the arc and at its center line. Jour. Applied Mechanics, June, 1938, pages A81–A85, 10 illus., 1 table.

Stress Model of a Complete Airship Structure. L. H. Donnell, E. L. Shaw, and W. C. Potthoff. Considerations in designing stress models in general, and the construction, rigging, and testing of an airship model in particular. New type of girder representation described has the unusual advantages of varying axial, bending, and torsional characteristics independently, and of incorporating convenient and sensitive means for measuring the corresponding stresses. Tests on a separate braced-ring model are compared with theory, and appear to be in good agreement. Similar tests on a duplicate ring in the complete model show influence of surrounding structure. Jour. Applied Mechanics, June, 1938, pages A67–A77, 19 illus., 1 table, 13 equations.

Torsion in Rectangular Spar-Boxes. H. Davies. Extension of the simpler problem of the torsion of a rectangular spar box to the case of the "interrupted" torsion box. Here an outer torsion box is attached at its roots to two spars, which resist torsion by differential shear and bending. Simple expression is derived to show the effect of free spars at the root on the distribution of shear stress and boom load in the box. Expressions for total strain energy which have been derived lend themselves readily to calculation of torsional deflection for the entire wing. Expression is given for the gain in stiffness (or reduction in deflection) for the box built in at the root, according to the ratio of torsional deflection of the built-in box to the Batho deflection. Aircraft Engg., July, 1938, pages 221–223, 5 illus., 3 tables, many equations.

Aircraft Alighting Gear

Aeroplane Undercarriages. E. Jones and F. G. R. Cook. Performance calculations for oleo-pneumatic shock absorber struts; equations of motion and their calculation; calculation of tricycle undercarriages; and drag loads on undercarriages. Current practice and notes on design. Aircraft Engg., July, 1938, pages 213–217, 7 illus., 1 table, many equations.

Hydraulic Pressure Regulating Device. Aircraft Accessories pressure-regulating device maintains the correct operating pressure of the hydraulic system in connection with the engine- or electrically-driven hydraulic pump and eliminates the necessity for manually operating bypass valves or the return of selector valves to neutral after completion of the operating cycles. Regulator automatically handles loads up to 1000 lb./sq. in., and automatically maintains a predetermined pressure on a hydraulic system at all times, either on one or two engine-driven pumps. Short description. Aero Digest, August, 1938, page 103, 1 illus. Aviation, August, 1938, page 41, 1 illus.

Aircraft Manufacture

The Drop Hammer Gives Aircraft a Lift. F. H. Rohr. Use of the drop hammer in the production of wing and fuselage parts at the Ryan Aeronautical Corporation is described. Am. Machinist, August 10, 1938, pages 714–717, 6 illus.

Aircraft

FRANCE

Airplanes in Test. Tests of the Delanne airplane (Régnier 180-hp. engine), recently completed, were very satisfactory. Loss of the Bréguel 730 flying boat has been greatly resented by the Aéronautique Maritime. Very brief notes on these aircraft and references only to the Bréquet 690 combat and light bomber and Le0-45 bomber (two Hispano-Suiza 14-AA engines) undergoing tests. Les Ailes, July 28, 1938, page 9.

The Last Flights of the Stabilized S.F.A.N. Airplane. Accident to the S.F.A.N. airplane controlled by the Billioque horizontal stabilizer while it was being flight tested by E. Billioque. Short note. Les Ailes, July 28, 1938, page 13.

Notes and Specifications of the Potez 661. Structure, distribution of payload, and design of undercarriage and other parts of the Potez 661 four-engined airplane (four Renault 6-Q engines) are illustrated in many drawings and photographs, and are explained in detail. Fuel-consumption curves are given. Potez 661 is compared with the Potez 662 (four Gnôme-Rhône 14 Mars engines) in a drawing. L'Aéronautique, May, 1938, pages 99–103, 22 illus.

Airplanes in Test. Very brief references only to the following military aircraft undergoing test: First issue—Le0-45 bomber (two Hispano Suiza 14-AA 1150-hp. engines supplied with new Mercier cowlings reducing engine temperatures). Bloch 150 single-seater two-cannon pursuit (Gnôme Rhône 14-No. 10–11, 870-hp. engine). Fifteen Potez 63 bimotored fighter convoy, observation, combat and light bombers. Second Bloch 131 bimotored bomber. Bréguet 690 combat and light bomber. Morane-Saulnier 406 (Hispano-Suiza 12-Yers 860-hp. engine cannon).

Second issue—Latécoère 523 Algol flying boat. Potez 630 bimotored fighter (two Hispano-Suiza engines). Nieuport 161 fighter (Hispano-Suiza-engine cannon). Bloch 133 bomber (two Hispano-Suiza 14-AA engines) derived from the 131 but having double rudders. Lignel 10 for training in piloting modern aircraft (Renault 6-Q engine). Les Ailes, July 14 and 21, 1938, pages 9 and 9.

At the Fête de l'Air. A unit of M.S.-406 airplanes in a dive. Photograph only. Les Ailes, July 21, 1938, page 1, 1 illus.

The Hanriot 510 Three-Seater Army Cooperation Airplane. A. Frachet. Hanriot 510 bimotored monoplane of mixed construction (two Gnôme Rhône K-9 750-hp. engines, speed 350 km./hr., and ceiling 7000 meters) has been designed for training and army cooperation purposes. Long description. Les Ailes, July 14, 1938, page 9, 3 illus., 1 table.

SE-200 Transatlantic Flying Boat. With six engines developing a total of 9000 hp. the 66-ton flying boat should reach a maximum speed of 400 km./hr. Carrying a crew of eight and 6000 kg. of freight the flying boat will be capable of transporting 42 passengers across the South Atlantic or 20 passengers across the North Atlantic. Description of interior layout of the flying boat with cutaway and other drawings. Les Ailes, July 21, 1938, page 8, 4 illus.

Technical Notes. Two new rotary-wing aircraft are being produced by the Société Française du Gyroplane which developed the Bréguet-Dorand patents. The G-10 is a two-seater which has two three-bladed rotors and a 300-hp. Hispano-Suiza engine. It should attain a speed of more than 200 km./hr. and will carry fuel for five hours. Brief reference. Les Ailes, July 14, 1938, page 7.

GREAT BRITAIN

The British Tipsy. New features of the British Tipsy two-seater airplane include mass balancing of the ailerons, elevators and rudders, a steerable tail skid, and small camber-changing flaps. Constructional features are discussed with drawings. Flying qualities are described in a second article. Airplane has a 60-hp. Walter Mikron engine. Top speed is 112 m.p.h. Aeroplane, August 10, 1938, pages 176–178, 12 illus.

New Aircraft Construction. De Havilland four-engined monoplane under construction is designed to carry 12 to 17 passengers and to cruise at over 200 m.p.h. Specifications have been outlined for an all-metal four-engined monoplane weighing 40,000 lb. and designed to carry 20 passengers nonstop from London to Berlin at a cruising speed of 200 m.p.h. Specifications have also been outlined for two versions of an all-metal four-engined landplane weighing 70,000 lb. and intended for high-speed long-range flights, one to fly at 10,000 ft. and the other, a high-altitude version with pressure cabin, flying at 25,000 ft. at 275 m.p.h. Brief note. Engineer, August 5, 1938, page 137.

A Mercurial Passage. New upper component of a composite aircraft is referred to which, without floats, struts and wires, ought to be started off at a speed of at least 300 m.p.h. and should cruise nonstop to India at something over 400 m.p.h. Latest story is that the new upper component is to be launched from the top of an Armstrong-Whitworth Ensign. Comments on the recent transatlantic flights of the Mercury, upper component of the Mayo composite aircraft, and references to a new component. Second article gives statistics on the Mercury's transatlantic flight. Aeroplane, July 27, 1938, pages 103, 121.

HOLLAND

The F.K. 55 Fighter Has Made Its First Flights. Koolhoven F.K. 55 fighter (Lorraine Petrel 12 Hars 860-hp. 12-cylinder vee liquid-cooled engine driving two concentric propellers). Brief reference only to tests. Les Ailes, July 14, 1938, page 5.

ITALY

Jona 6-S Biplane with Oscillating Wing Is Being Constructed in Series for the Italian Air Force. Jona 6-S two seater with double control (Alfa Romeo 240-hp. engine) can be used as a training airplane or for reconnaissance missions when it is equipped with a machine gun, radio, aerial photographic equipment and oxygen inhalers. Range 3 hours, maximum speed 255 km./hr. at 3000 meters, and ceiling 8000 meters. Short description. Les Ailes, July 28, 1938, page 5, 1 illus.

POLAND

The P.Z.L. Wicher Transport. A. Frachet. All-metal commercial prototype of the new P.Z.L.-37 bomber is powered with two 850-hp. Wright Cyclone engines and carries 14 passengers, a crew of four and 400 kg. of freight. Maximum speed 377 km./hr. at 2000 meters, cruising speed, 324 km./hr., and range 1800 km. Les Ailes, July 28, 1938, page 9, 3 illus., 1 table.

A Polish Commercial Aeroplane. P.Z.L. Wicher 14-passenger monoplane intended to replace the American Douglas and Lockheed airplanes now used on the Polish airline Lot. Powered by two Wright Cylcone G-2 engines, the airplane has a maximum speed of 234.6 m.p.h. at 6560 ft. and range of 1144 miles at 62.5 percent power. Description and characteristics. Aircraft Engg., August, 1938, page 251, 3 illus., 1 table.

U. S. A.

A Unique Tailless Design. Bumblebee being tested by J. B. Taylor, Jr., is a tailless airplane without sweepback. Long flaps run along the whole length of the wing with auxiliary or trimmer surfaces behind them. Simultaneous depressing or raising of the flaps on either side gives elevator action, and raising the flap on one side and depressing the flap on the other should give aileron or lateral control. Steering is no doubt achieved by using the vertical surfaces at the tips of the wings as drag elements. Airplane is powered by a 95-hp. engine driving a pusher propeller. Short discussion of how static longitudinal stability is attained. Scientific American, August, 1938, pages 142–143, 3 illus.

Bennett BTC-1 Bi-motored "Executive." Twin-engined six-seater midwing cabin monoplane constructed throughout of Bakelite plywood, is stressed to take engines ranging from 285 to 450 hp. With two 285-hp. Jacobs L-5 engines, maximum speed is 206 m.p.h., cruising speed 196 m.p.h., at 8000 ft. and cruising range 1176 miles. Aero Digest, August, 1938, pages 100, 116, 5 illus., 1 table.

Curtiss-Wright Model 20 Transport. Curtiss Model 20 midwing all-metal bimotored transport airplane designed to carry 30 passengers, a crew of 4 and a heavy load of baggage, express and mail in compartments totaling 600 cu. ft. (Subsequent designs are to have berths for 29 passengers). Pressurized passenger and pilot compartments will assure comfort to personnel aboard when operations are conducted in the substratosphere. Estimated performance with two 1600-hp. Wright double-row Cyclone engines: maximum speed 237 m.p.h. at 12,000 ft., cruising speed 200 m.p.h. at 10,000 ft., and service ceiling 33,000 ft. Long description. Aero Digest, August, 1938, pages 48–49, 116, 6 illus., 1 table. Description by T. P. Wright, with special reference to safety features. Aviation, August, 1938, pages 29–31, 42, 46, 78, 9 illus.

Howard Hughes' Lockheed 14 Monoplane used for the Record Breaking World Flight. Noticeable differences between Howard Hughes' around-the-world airplane and the standard Lockheed 14. Interior arrangement, forward compartment, and engines are described. Photographs and cutaway drawing snowing location of equipment. Aero Digest, August, 1938, pages 46–47, 68, 4 illus.

Phillips Aeroneer Two-Place Metal Ship Receives Type Certificate. Aeroneer low-wing cantiliver monoplane seating two people side by side in an enclosed cabin (Menasco C4 125-hp. engine, top speed 129 m.p.h.). Tendency to drop a wing during early flight tests, due to effect of tip stall with consequent loss of aileron control, was overcome by adding "bulges" to the leading edge of each wing panel along the portion forward of the ailerons. Aeroneer is now being fitted with the Menasco B6 160-hp. engine and with slightly larger outer wing panels. Upon completion of flight tests, the more powerful model will be taken to Wright Field and to Randolph Field for an extensive test period to determine the desirability of using this type as a primary trainer. Aviation, August, 1938, page 35, 1 illus.

U. S. S. R.

On Two Soviet Aviation Performances. Flight of Kokinaki and Briandinski from Moscow to Spask in a Tsekabe 25 bimotored bomber (M-85 engines, licensed Gnôme-Rhône K-14s) covered 6850 km. at an average speed of 279 km./hr. A flight of 2146 km. was made by three women from Sebastopol to Archangel at an average speed of 228 km./hr. in a M.P.-1 seaplane, civil version of the M.B.R.-5 two-seater reconnaissance naval seaplane (M-34 engine). Description of flights. Les Ailes, July 28, 1938, pages 5–6.

Aircraft Accidents

The Accident at Cherbourg. A new four-engined Bréquet 730 flying boat designed for exploration recently crashed during a test flight. It is said that the four engines did not respond to the controls and the flying boat lost speed and went into a dive. Brief note. Les Ailes, July 21, 1938, page 3.

Air Ministry Official Notices. Notices referring to a recent accident to a Monospar S.T. 25 indicating confusion may occur in determining whether the gasoline cock is on or off, and to a failure of a wooden propeller fitted to an airplane with an Aeronca J.A.P. engine. Aircraft Engg., July, 1938, page 227.

Air Transportation

Imperial Airways and the North Atlantic. List of flights to be made with probable dates, airplanes to be used, and routes to be flown. Aeroplane, July 27, 1938, page 121.

Airships

French Helium. Reason why helium has not been produced in France. Les Ailes, July 28, 1938, page 8.

Lighter-Than-Air. Navy's new experimental airship will be 650 ft. long and will have a maximum diameter of 100 ft. Less than half the 6,500,000 cubic capacity of the Akron and Macon, the new airship will have a capacity of 3,000,000 cu. ft., only slightly more than the old Los Angeles. Short note. Aero Digest, August, 1938, page 44.

The Zeppelin Co's Joke on America. C. G. Grey. Comments on refusal of the United States to export helium to Germany, rumors of a gas developed by the I. G. Farbenindustrie and said to be better than helium, and use of airships in general. Aeroplane, August 10, 1938, pages 165–166.

Gliders

Development of Sailplanes. Sq. Ldr. G. M. Buxton. Paper and discussions following. Royal Aeronautical Soc., Jour., August, 1938, pages 653–678 and (discussion) 678–700, 12 illus., 3 tables, many equations.

Some Sailplane Design Data and Information from German Sources. B. S. Shenstone. Drags of sailplanes, methods of measuring performance, and measurements of sinking and air speeds; structural weight of sailplanes; air brakes for use in diving; and structural notes on the Habicht aerobatic sailplane, stressing assumptions, effect of increased loading on the design in general and on the structure, testing, and metal construction. German strength requirements for sailplanes are discussed in detail in regard to: nature of regulations; safety; strength calculations; loading due to air forces, to ground forces, and to hand and foot forces and other loads; and formulas and methods for carrying out strength calculation. Long article. Journal Royal Aeronautical Soc., August, 1938, pages 701–734, 39 illus., 3 tables, many equations.

Propellers

Estimating Thrust Horse-Power. J. G. Willis. Charts and notes on propeller data which have been found useful in the design office for performance estimation. Chart for finding the solution of an equation for speed-power coefficient, chart for propeller selection based on NACA Report No. 564, charts for power coefficient *versus* V/nD for blade angles at 0.75 radius, chart for quick solution of power coefficient, and other charts are given and discussed with examples of their use. Aircraft Engg., July, 1938, pages 206–211, 10 illus., 8 tables, many equations.

Little Controllable Props. S. Calkins. Opinions of various propeller manufacturers on the possibility of producing small controllable-pitch propellers for light airplanes, and a few details only of the Maynard-di Cesare offset propeller and the Everel single-blade propeller. Western Flying, August, 1938, pages 19–21, 2 illus.

Air Ministry Official Notices. Propellers and the engines and aircraft for which their use is approved are listed in a three-page table. A brief notice is also given drawing attention to the need for guarding against effects of poisonous fumes when using chemical fire extinguishers of the types usually carried on British civil airplanes. Aircraft Engg., August, 1938, pages 255–257, 258, 1 table.

New Propeller Controlled by Heat. Controllable-pitch propeller developed by N. E. G. Meijer of the General Electric Company. Mechanism is enclosed in the propeller hub and change in pitch is effected by heat generated by an electric coil. Heat causes metallic cylinders telescoped within one another to expand. These sleeves are connected to the pitch-changing mechanism and are heated by an electric heating coil. In another patent, force to change the pitch is derived from a metal bellows filled with a liquid of high coefficient of expansion, and in a third patent exhaust gases are used as a source of heat. Short description. Western Flying, August, 1938, page 32.

Oppositely Rotating Propellers Tested. War Department announcement regarding tests at Wright Field on oppositely rotating propellers. U. S. Air Services, August, 1938, page 34.

Photograph and reference to advantages. Aviation, August, 1938, page 66, 1 illus.

Rockets

A.R.S. No. 2 Proving Stand. J. Shesta. American Rocket Society's new proving stand is described, covering feed system, fuel measurement, thrust measurement capacity of the stand, scope of work, and performance ranges. Astronautics, April, 1938, pages 15–17, 1 illus., 3 tables.

Dry Fuel Experiences. P. Van Dresser. Experiments to determine the most suitable placing of the rocket motor in the rocket, and interesting results with parachute and release employed. Astronautics, July, 1938, pages 9–12, 3 illus.

Fuel as Coolant. J. H. Wyld. New self-cooled tubular regenerative motor for rockets. Brief description. Astronautics, April, 1938, pages 11–12, 1 illus.

Gas, Air, Water. R. C. Truax. Unusual experiment with a rocket motor using compressed air and gasoline as fuels. Fuel was injected and atomized by a centrifugal whirl. Nozzle was cooled from entrance to throat by gasoline circulation in a double-walled portion and from throat to mouth by water injected through an annular orifice. Air supplied under 700 lb./sq. in. forced the water and gasoline into the chamber. Description of tests. Astronautics, April, 1938, pages 9–11, 2 illus.

Landing Gear Releases. J. Shesta. Requirements of parachute or other landing gear releases for use on liquid fuel rockets. Ejecting the parachute, gas ejection, advantages of wings, trigger mechanisms, utilizing gravity, the A.R.S. No. 4 rocket release, barometric methods of release, release design, and release by gyro are discussed. R. Tiling's patented design is illustrated. Astronautics, April, 1938, pages 3–7, 12, 5 illus.

Rocketry in California. Plans and progress of the Rocket Research Group at the Guggenheim Aeronautical Laboratory, California Institute of Technology. Drawings show the rocket motor test stand and a proposed experimental carbon-lined motor. Astronautics, July, 1938, pages 1, 3–6, 5 illus.

Projectiles

The Flight of the Projectile. R. H. Kent. Flight of the projectile in the bore, with data on partial pressures in atmospheres of constituent gases resulting from burning of two different types of powder under various total pressures; maximum theoretical velocity of a gun; and flight in the air. Long discussion. Franklin Institute, Jour., July, 1938, pages 19–33, 11 illus.

Equipment

Army Air Corps Rescue Boats. Greenport P-11 high-speed rescue boats developed for the U. S. Army Air Corps for operations off Oahu, Hawaiian Islands, in open sea and inter-island patrol. Boat measures 72 ft. overall in length. Powered by twin 12-cylinder 600-hp. Capitol-Wright engines, it has a speed of 31 m.p.h. Few details. Aero Digest, August, 1938, page 103.

Flexible Light-Weight Fuel and Oil Lines. Chicago Avioflex fuel and oil lines utilizes a flexible metal core protected by a duPont cellophane laminated cellulose film and a neoprene chloroprene rubber. Short note. Aero Digest, August, 1938, page 103. Western Flying, August, 1938, page 32, 1 illus.

Floats made of Balloon Fabric. Built of Goodyear airship fabric and inflated to 3 lb./sq. in. air pressure in each of the five compartments built into each float, the new gear is light in weight, impervious to rust and corrosion, and has operational resiliency. Few details. Aero Digest, August, 1938, page 104, 1 illus. Western Flying, August, 1938, page 32, 1 illus.

Resistoflex Flexible Tubing for Oils, Gasoline and Organic Solvents. "Resistoflex" PVA tubing, available in sizes up to 1/2 in. inside diameter, is made of a flexible synthetic resin, polyvinyl alcohol, which is not only inert to gasoline and oils, but retains its flexibility throughout a wide temperature range. Aviation, August, 1938, page 41.

24 Volts—50 Cycles. Ducellier company will construct an American 110-volt 800-cycle generator for French aircraft under a Bendix license. This type is discussed and opinions of L. L'Hopitault are quoting regarding his preference for the use of 24-volt 50-cycle current on board aircraft. Les Ailes, July 28, 1938, page 7.

Electrical Equipment in Aircraft. Advice to ground engineers on the location and remedy of troubles with electrical equipment on aircraft. Tables show how to locate and remedy constant-voltage and constant-current dynamo and lighting troubles. Aircraft Engg., August, 1938, page 258, 2 tables.

Aeroplane Landing Lights. E. S. Calvert. Principles to be followed in the installation of lights in airplanes. Method of landing with the light; lights with controllable beams; lights for seaplanes; beam setting for airplane lights; ground reconnaissance; beam setting adjustment; shape of beam; position of light on aircraft; and wattage and size of light required. Aircraft Engg., August, 1938, pages 237–242, 15 illus.

Miscellaneous

The Freedom of Frankfurt. F. D. Bradbrooke. Account of German meeting and the exhibition flying and air racing events at Rhein-Main Airport. Aeroplane, August 10, 1938, pages 181–183, 6 illus.

An Institute Has Been Organized at Turin for the Study of "Muscular Flight." P. H. Monand. The V.U.M. Institute has been organized in Italy to study the problem of designing engineless airplanes having a manually-operated propeller. Description of organization. Les Ailes, July 21, 1938, page 12.

Reasons for the Success of the N.A.C.A. P. Dumanois, Inspector General of Aeronautics. Organization and work of the N.A.C.A. from the French point of view. Les Ailes, July 21, 1938, page 7.

Production of Helium at Amarillo. C. W. Seibel. Developments in the production of helium, steps in the process, economics, and uses other than that for airships. This article is preceded by one by H. P. Cady entitled "Beginnings of the Helium Industry." Industrial and Engineering Chemistry, Ind. Ed., August, 1938, pages 845–852, 10 illus.

91 Hours, 8 Minutes, 10 Seconds. Howard Hughes' own summary of his recent world flight as delivered over NBC in response to his New York ovation. Second article describes plan, crew, and flight. Cutaway drawing shows location of equipment in the airplane. Aviation, August, 1938, pages 20–27, and 53–54, 6 illus.

The Record Flight of Hughes and Crew Around the World. H. L. Lewis, II. Details of the flight. U.S. Air Services, August, 1938, pages 15–16, 1 illus.

AIR RACES

The National Air Races, Cleveland, Ohio, September 3 to 5. Events planned are described. Aero Digest, August, 1938, pages 83, 88. U.S. Air Services, August, 1938, page 25.

Changes in rules for the Races and some of the airplanes being prepared. Western Flying, August, 1938, page 16, 1 illus.

New Rules Push Soarers to New Marks in Ninth Elmira Contest. Account of the Soaring Society's Ninth Annual Soaring Contest. Aviation, August, 1938, pages 52–53, 4 illus.

Fuels and Lubricants

Improvements in Diesel Engine Lubricating Oils. U. B. Bray, C. C. Moore, Jr., and D. R. Merrill. Outstanding lubricating difficulties experienced with modern medium and high-speed Diesel engines lubricated with straight mineral oil are discussed, including ring sticking, scratching or scuffing, excessive wear, and bearing failures. Properties of lubricating oil necessary for alleviating these lubricating difficulties are considered in detail, namely, detergency, high film strength, high degree of oiliness, low carbon-forming tendency, stability against oxidation and engine temperatures, and noncorrosiveness to engine bearings.

Progress made in overcoming deficiencies of straight mineral oils through the use of soap-type addition is pointed out. A simple method of evaluating compounding agents for detergent properties at least under one set of temperature and concentration conditions is described. Tables give laboratory inspection data on samples of commercial Diesel-engine oils and results of field tests of Diesel-powered tractors using compound oil containing calcium dichlorostearate. S.A.E. Preprint for meeting, June 12–17, 1938, 14 pages, 2 tables.

Engine Design and Research

Heat Dissipation Through an Annular Disk or Fin of Uniform Thickness. W. M. Murray. Equations are developed for expressing temperature distribution and heat transfer of an annular disk of uniform thickness when heat is being received through one edge, whose temperature is known, and transmitted to the surrounding medium through the exposed surfaces. Problem is considered from the point of view of finding the heat transfer from a circular fin of uniform thickness which is added to a tube for the purpose of increasing heat transfer. Jour. Applied Mechanics, June, 1938, pages A78–A80, 2 illus., 13 equations.

An Important Element of the Aerodynamic Balance of the Airplane. A. Verdurand. Study of the operation, as a reaction engine, of the cowling and deflectors of air-cooled engines. Conditions include: design of cylinder deflectors and air passages to obtain as reduced a speed as possible around the cylinders as well as maximum pressure; design of an expansion tube up to the rear slot of the cowling to complete expansion up to the pressure at the rear of the slot, as well as to avoid formation of internal eddies, and to direct all steamlines parallel to the external wall at rear of the nacelle; to regulate the quantity of air delivered to bring the cylinder-wall temperature up to maximum which can be supported without danger; and flying at as high an altitude as possible. Parts of A. H. R. Fedden's S.A.E. paper (October, 1937) on increase of drag due to fairing of engines are quoted. L'Aéronautique, L'Aérotechnique Sup., May, 1938, pages 66–69, 4 illus.

Automotive Two-Cycle Diesel Engines. E. G. Shoemaker. Present status of the automotive-type Diesel engine; limitations to increased output; two-cycle design problems; two-cycle power; scavenging; exhaust back pressure; blower noise; piston cooling; injection system; two-cycle engine balance; and commercial design problems. S.A.E. Preprint for meeting June 12–17, 1938, 21 pages, 10 illus., 4 tables.

Diesels in the Air. P. H. Wilkinson. "Next year, or the year after, may see the advent of the 2000-hp. Diesel in huge airliners for flights across the ocean. Based on their highly successful Jumo 205, Junkers has already its 1200-hp. Jumo 206 on test." The Junkers 2000-hp. engine, to be completed by the end of the year, will be a 24-cylinder square engine of 39-in. diameter. Fuel consumption will not exceed 0.34 lb./hp.-hr. and weight is said to be little more than 1 lb./hp. Operating on the two-cycle principle at 3000 r.p.m., it will have 144,000 power impulses per minute from its 48 pistons. Reference is made to this engine in an account of the use of Diesel engines on the Deutsche Lufthansa. Diesel projects being developed for aircraft in the United States, England, France, Italy and Russia are also mentioned. Scientific American, September, 1938, pages 117–119, 4 illus.

Heat Transfer Coefficients in Staggered Tube Banks. C. C. Winding. Influence of tube shape. Heat transfer coefficients from condensing steam to air are given for staggered banks of round, oval and streamline tubes. Latter should give a much lower pressure drop but data show that this advantage is offset by lower coefficients of heat transfer in all rows except the first and second. Oval tubes give definitely lower rates of heat transfer than either of the other two shapes. Data for round tubes are compared with various relations proposed to correlate air-film coefficients with variables influencing rates of heat transfer. Industrial and Engineering Chemistry, Ind. Ed., August, 1938, pages 942–947, 8 illus, 1 table.

Some Recent European Developments in High-Speed Diesel Engines. P. M. Heldt. Development work on aircraft Diesel engines which has been carried out in England, France and Germany is discussed in the last part of the paper, the first part being devoted to European automobile, truck and rail-car Diesels. An automatic timing device for injection pumps, developed by Saurer, and a special engine indicator of the electric type developed by the Saurer research department for use with Diesel engines are described. S.A.E. Preprint for meeting, June 12–17, 1938, 23 pages, 10 illus.

Surface Finish Related to Wear in Internal-Combustion Engines. K. W. Connor. Combined characteristics of surface character and finish in engine bearing and operating parts may now be determined practically and efficiently by means of the new portable Profilometer, combined with photographic or microscopic study. Details of the Profilometer; cylinder-bore processing; surface roughness as related to oil consumption; effects of machining metal as related to structural deformation; results obtained by mechanically and hydraulically actuated honing tools; processing variation; and simplified processing. S.A.E. Jour. (Trans.), August, 1938, pages 305–312, 11 illus.

Torsional Vibration of In-Line Aircraft Engines. R. M. Hazen and O. V. Montieth. Paper previously abstracted from preprint. S.A.E. Jour. (Trans.), August, 1938, pages 335–341, 12 illus.

Engine and Fuel Testing

Correlation of Road and Laboratory Octane Numbers. J. R. Sabina. Object of the study described was to coordinate results obtained by the Road and Laboratory groups and to develop, if possible, a better method for correlating road and laboratory procedure. Report from the Cooperative Fuel Research Committee. S.A.E. Preprint for meeting, June 12–17, 1938, 18 pages, 9 illus, 4 tables.

Smokemeter of Simple Design Tests Diesel Combustion. Smokemeter developed in the Diesel laboratory of Pennsylvania State College consists of a tube of 2-in. inside diameter and 18-in. length with a glass window at each end, there being a 100-watt projector lamp at one end, an adjustable shutter interposed between lamp and window, and a G.E. pocket-type light-meter at the other end. Description of smokemeter. Automotive Industries, August 20, 1938, page 238, 2 illus.

Engine Testing Equipment

Measurement of Detonation. F. Postlewaite. Royal Aircraft Establishment-Mullard detonation unit located in the cylinder head is operated on directly by cylinder gases and is arranged to deliver electrical impulses along a

cable to the detonation meter. Farnborough cathode-ray pressure indicator; electrical filters for detonation measurement including high-, low-, and bandpass filters, conditions to be fulfilled by the detonation unit; piezo-electric effect and other characteristics of quartz; design features of the detonation unit; amplifying and filtering circuit; gas discharge triods; measuring; resetting circuit controls and terminals of the R.A.E.-Mullard detonation meter; and measurements made with the meter. Aircraft Engg., July, 1938, pages 201–205, 211, 18 illus., 5 equations.

Structural Design of Test Stands for Aircraft Engines. W. von der Nuell and E. Heinrich. Requirements of aircraft-engine test stands for acceptance tests, research and development, high-altitude tests, single-cylinder tests, tests of engine structural groups. Drawings include; fundamental construction for soundproof test stand; Hirth soundproof test stand with special arrangement of guide vanes and exhaust for exhaust gases; D.V.L. elastic engine mount; cross section of DVL building with several test stands for tests of liquid-cooled engines, English Alvis and German test stands with blower; large sound-proof test stand with double deflection of air guides at inlet and outlet; Fiat high-altitude test stand. Also photographs of D.V.L. service control board and a complete D.V.L. single-cylinder test installation. V.D.I., June 11, 1938, pages 714–718, 14 illus.

Engines

Alfa-Romeo Has Constructed a New Diesel. Two models of six and twelve cylinders in vee having 5.5 and 11.1 liters and developing 110 and 220 hp., respectively. Tangential scavenging ports are disposed at the end of the stroke and exhaust is by two valves in the head. Hollowed head of the piston carries a small plate of special metal which, in normal operation is raised to very high temperature. Jet of the injector is projected on this plate resulting in instantaneous vaporization. Short description. Les Ailes, July 28, 1938, page 7.

A New Direct Injection Oil Engine. Associated Equipment Company's direct-injection automotive oil engine. In addition to rotary movement produced by the masked or shrouded inlet valve, air is forced violently toward the center of the cylinder as the piston nears the end of the compression stroke, cutting through four fuel sprays and continuing downward into the cavity with a whirlpool motion. Stream then diverges at the bottom of the cavity following the specially shaped walls to emerge into the main cylinder as combustion is completed and as piston descends on its working stroke. Description of this engine and of the Ricardo Comet engine. Engineer, July 29, 1938, page 120, 4 illus.

Unitwin Power Flight Tested. Unitwin Power consists of two Menasco C6S4 inline engines, each of 260 hp., geared to a single constant-speed propeller through a gear box and over-riding clutches. Clutches are similar to over-riding clutches used in automotive "free-wheeling" and provide completely automatic engagement and disengagement of engines and propeller. For initial flights the Unitwin powerplant was mounted in a special Lockheed Altair fitted up as a flying laboratory. Description of power plant and results of flight tests. Aviation, August, 1938, pages 32, 35, 2 illus. Few details. Western Flying, August, 1938, page 36.

The DeHavilland Gipsy-Twelve—A British Low Frontal-Area Unit. Crankshaft and supercharger drive assembly, supercharger gearing and casing, and the engine itself are illustrated. Characteristics and curves for horsepower developed at different altitudes for various flight conditions are given. Engine is an inverted-vee 12-cylinder type developing a maximum of 505/525 hp. at 3600 r.p.m. at +3.5 lb. boost for take-off. Aircraft Engineering, August, 1938, pages 248–249, 5 illus., 1 table.

Technical Notes. The Gadoux engine cannon, previously described, is being constructed by the Regnier firm. It is a barrel engine with two concentric propellers, a cannon firing through the propeller hub, and reduction gear. Brief reference. Les Ailes, July 14, 1938, page 7.

Parts and Accessories

Development of Modern Exhaust Collector Rings. F. H. Rohr. Two critical problems solved by the Navy because of its inability to use the black iron collector rings then available; mill technique improvement; and Ryan manufacture of stainless steel exhaust silencers for Air Corps attack-bombers and British bombers. Various steps taken in the fabrication of exhaust collector rings are described. Aero Digest, August, 1938, pages 84, 87–88, 11 illus.

Materials

Research on Materials and Modern Design. A. Thum. Difficulty in determining working loads for designing; notch effect under different stresses; rules for attainment of high structural strength; absorption of impact stresses; time resistance; the damage line; and high service temperature. Engineering, July 29, 1938, pages 143–146, 13 illus.

Bearings

Influence of Pressure on Film Viscosity in Heavily Loaded Bearings. S. J. Needs. Phenomenon of heavily-loaded bearings indicating an increase in film viscosity due to pressures in the oil film supporting the load. Various bearing metals and lubricants were investigated in Dr. Kingsbury's laboratory to determine their behavior under heavy loads. Testing machine is described and test results discussed. Mathematical explanation of the phenomenon is offered in the calculation of the effect of viscosity increase under pressure on the operating characteristics of plane surfaces of infinite width. Test and calculated results compared. A.S.M.E. Trans., May, 1938, pages 347–358, 22 illus., 1 table.

Automotive Bearing Materials and Their Application. A. F. Underwood. Future bearing materials will give higher fatigue life than the popular white metals and will have their anti-score characteristics. They will be noncorrosive and less susceptible to dirt and deflections. Bearings will be designed for higher load factors as these materials are developed. Discussion covers: various properties which make a good bearing alloy, especially fatigue strength; functional differences of tin-base babbitt, lead-base babbitt, hardened lead, cadmium, silver, and copper-lead; and bearing design factors (mechanical items). S.A.E. Preprint for meeting June 12 to 17, 1938. 12 pages, 1 illus.

Metals

Exhaust Manifold Metal. J. M. Weldon. Properties of Inconel, and its use with good results for firewall of the Lockheed 14 airplane, in the section forward of the firewall, and for sheathing. Aero Digest, August, 1938, page 95.

Magnesium Alloys and Their Use in the Production of Aircraft and Engine Parts. A. W. Winston. Application of magnesium sand castings, permanent mold castings, pressure die castings, forgings, and extruded and rolled parts. Table shows composition, typical mechanical properties and uses of magnesium alloys. Long abstract of Western Metals Congress paper. Aero Digest, August, 1938, pages 50–52, 5 illus., 1 table.

Testing of Metals

Microstructural X-Ray Testing. A. Kufferath. Some devices used are described and applicability of the method to aircraft manufacture is pointed out. Microstructural analysis is recommended for the study of all manufacturing processes of airplane parts made of aluminum or magnesium alloys of engine parts made of steel, and of many tools, and likewise for the study and control of various manufacturing processes such as hardening and annealing of high-speed tool steel, pistons and rings. Nitrohardening process can be successfully controlled by microstructural analysis.

One new instrument described, which was developed in the Siemens-Halske works, operates with a 15 mA and a maximum tube crest tension of 45 kv. It is shown that microstructural examinations can also be carried out by the Debye-Scherrer and by the rotating crystal processes by the reflection method used in connection with larger sized objectives and, to a smaller extent by the Laue method. Metalix small X-ray instrument constructed at the N. C. Philips' Gloeilampenfabrieken and the Rich Seifert instrument are also described and advantages offered by comparative X-ray examinations are illustrated. Aircraft Engg., August, 1938, pages 252–254, 8 illus.

Rubber

Synthetic-Rubber Substitutes. T. L. Garner. Properties, especially oil resistance, of the German Buna synthetic rubbers (N, S, 85, 115) and Perbunan, Neoprene, and the alkylene polysulphide products. Only the N type is satisfactorily resistant to oils and benzine but all Buna rubbers are considered superior to ordinary rubber in resisting wear. Best type of Perbunan mix gives better results than can be obtained from Neoprene mixes. Oil resistance, noninflammability, shock absorption and other properties of importance to the aircraft industry are pointed out. Aircraft Engg., July, 1938, pages 212, 217, 1 illus., 2 tables.

Testing of Materials

Viscosity Measurement. M. R. Cannon and M. R. Fenske. Operating characteristics of simple modified Ostwald viscometers suitable for covering a wide range of viscosity with accuracy. Important sources of error in capillary viscometers are analyzed and equations for computing corrections given. Ostwald viscometer is compared with other types of capillary viscometers. Industrial and Engg. Chemistry, Anal. Ed., June 15, 1938, pages 297–301. 3 illus., 1 table, equations.

Acoustics

The Reduction of Structure-Borne Noise by Vibration-Attenuating Supports. A. J. King. Principles underlying the design of resilient supports, and more detailed information on the elastic properties of suitable materials than was given in the previous article. Definitions and formulas for elastic properties of materials in simple extension and compression are presented. Tables show elastic properties of soft-rubber sheet, felt and cork and their creep and incremental stiffness with time. To be continued. Engineering, July 29, 1938, pages 124–126, 4 tables, 5 equations.

Aircraft Instruments and Navigation

Automatic Instrument Log. Fairchild apparatus to provide a continuous photographic record of instruments and control positions in an airplane cockpit. Two camera and light assemblies, one containing a timing mechanism, and a control box are all connected together and to the plane's battery by means of radio-shielded cables. Condensing lens and infra-red filter for the lamp and an infra-red filter for the camera are mounted on the cover of the unit. Aviation, August, 1938, page 37, 2 illus.

Combination Time-Piece. Jardur Multi-Chron combination wrist-watch, stop-watch, tachometer and telemeter compacted into a single unit. Few details. Aero Digest, August, 1938, page 103.

A Direct-Reading Radio-Wave Reflection-Type Absolute Altimeter for Aeronautics. S. Matsuo. By use of a new principle, frequency modulation, for indicating the absolute altitude of aircraft with respect to the ground, the following results have been obtained; completely continuous indication of altitude by a steady pointer and dial is easily accomplished and altitude variations occurring during time intervals of a few milliseconds are clearly detected; very small altitudes, less than four meters, are indicated quite easily; indication is quite linearly proportional to altitude. Absolute error is zero and relative error is less than a few per cent. Altitudes in excess of 160 meters can be measured with a power consumption of only 3.9 watts. Description of apparatus developed and research at Tohoku Imperial University, Japan. Inst. Radio Engrs., Proc., July, 1938, pages 848–858, 12 illus.

The Fairchild-Maxson Line of Position Computor. J. D. Peace, Jr. Line of Position Computor automatically relieved the navigators of the Hughes' flight of the task of making the mathematical computations necessary to reduce celestial observations to a Line of Position or a Fix. Description of instrument now being produced in quantity for the Air Corps. Aero Digest, August, 1938, pages 67–68, 3 illus., Aviation, August, 1938, pages 49, 77, 1 illus.

Improved Sensitive Altimeter. Side-window barometric scale offering more easy readings and a quicker and more precise setting, has been incorporated in the newest type of Kollsman sensitive altimeter. Larger barometric dial numerals are placed alongside their corresponding graduations. Few details. Aero Digest, August, 1938, page 104, 1 illus. Aviation, August, 1938, page 41, 1 illus.

Testing Airplane Instruments in the Field. Portable equipment developed by the Materiel Division of the Air Corps to check the accuracy of airplane instruments on the airplane. Scientific Am., August, 1938, page 86, 2 illus.

Navigation

Hughes' Flight Navigators and Navigation Procedure. Three methods of navigation were used: celestial for position fixes, dead reckoning for flight between fixes, and radio direction finding for getting into the airport on the nose and for radio bearings when the sky was not visible. Previous accomplishments of the two navigators, preparations for the flight, methods used, and equipment carried are described. Needed improvements are discussed. Aero Digest, August, 1938, pages 63–64, 2 illus., 1 table.

Orientation and Landfall by Means of Precomputed Curves. Lt. W. C. Bentley, Jr. Method of precomputing curves for a long overwater flight in the daytime and of taking and plotting observations during the flight. Aero Digest, August, 1938, pages 92, 95, 2 illus.

Meteorology

Howard Hughes Weather. D. Sayre. Method used by W. C. Rockefeller in providing weather information for the flight. Aviation, August, 1938, pages 23, 77.

Meteorology Study Assisted. Haynes density channel developed at the Boeing School of Aeronautics as a visual aid to show the action that takes place when warm and cold air meets in cyclonic storm areas. Short description. Western Flying, August, 1938, page 44.

Aircraft Radio

Experimental Demonstration. The R.10 fighter-type short-wave transmitter and receiver of the Standard Radio Company, having four preset wavelengths, varying between 40 and 120 meters and set before leaving the ground; the R.9 direction-finding equipment produced either as a plain homing device or as a self-contained direction-finding station; the R.C.5 radio compass; and the two-way medium-wave equipment made up of the AT.14 transmitter and R.2 receiver, the six most used wavelengths being fixed. Description of this British radio equipment which is carried in the Heston Phoenix airplane used by the company for demonstration and test work. Equipment located in the airplane is illustrated. Flight, September 1, 1938, pages 184b–184d, 4 illus.

Training Aircraft Operators. J. A. McGillivray. Radio equipment used and aircraft radio instruction given at the Air Service Training, Ltd. Short description. Wireless World, July 14, 1938, page 27, 2 illus.

Aircraft Radio. Instrument-landing progress on the Metcalf-M.I.T. System. IT & T blind-landing contract for Bureau of Air Commerce. RCA Models AVR-8D and 8E compass with control-panel changes. Lear Unihand antenna reel and tuning unit. Brief descriptions. Aviation, August, 1938, page 38, 1 illus.

Radio Around the World on the Hughes Flight. H. W. Roberts. Radio ground stations at the World's Fair Flight Headquarters. Any of the six available receiving antennae could be instantly connected to any one of the six receivers. Four National Company HRO receivers were used, each covering the range from 175 to 30,000 kc. with 7 removable 4-coil units. Three transmitters were employed. Flying radio equipment also described in detail. Aero Digest, August, 1938, pages 56, 59–60, 6 illus., 1 table.

Book Reviews

Getting a Job in Aviation, by CARL NORCROSS; McGraw-Hill Company, New York, 1938; 374 pages, $2.50.

The need for a book of this type is given succinctly in the preface: "Aviation is occupation number one among young men in America. Medicine, law, engineering, and other popular occupations have been surpassed in their appeal by aviation. Its attractions combine the rugged adventure of seafaring, the thrill of railroading, the technical appeal of engineering and radio, and the commercial clarion of big business. For young men of today all the magnetism of past vocational favorites is rolled together, with a plus factor of achieving something which man has been trying to do for 2,000 years—to fly."

Those engaged in any kind of aeronautical activity know from experience the large number of young men who wish to enter the aviation field. They also know how few applicants have any idea of what kind of work they are fitted for. Mr. Norcross, by personal investigation, has analyzed all branches of the industry and gives prospective workers the information they should have to select the job for which they are best fitted by training, experience, or natural aptitude.

The book will be as helpful to those whose advice is sought regarding the opportunities in aviation as it will to those who are seeking jobs. Heretofore it has taken much time to explain the many kinds of work done by the airlines, manufacturers, and operators. Now a young man can learn from this study the probable requirements of any specialized field, the training required, and the nature of the occupation.

Even to those who have had long contact with aviation the book will be surprising. The field has expanded so rapidly that it has been almost impossible to know all of the various activities of the sixty thousand persons engaged in the industry. This book not only covers the whole field but shows, by its careful advice to young men, that it embodies the results of close personal contact with the leaders in each field.

Perhaps the most important influence the book will have will be to warn overly optimistic young men that the American aeronautical industry is not absorbing talent that has not had proper training. The advice given about the selection of places to secure the best educational advantages is sound and will be worth the cost of the book alone to any young man who is thinking of making aviation his life work.

Mr. Norcross estimates that the industry will employ between 100,000 and 120,000 persons by 1943. To give the additional personnel required good advice as to the best approach to employment is the purpose of the book. It will save those in the industry much time and give newcomers the information they should have before they apply for positions. Mr. Norcross has rendered a genuine service to the industry in compiling such a useful handbook.

VH-UXX, by P. G. TAYLOR; Angus and Robertson, Sydney, 1937; 298 pages, 8s. 6d.

When Captain Taylor visited the office of the Institute and saw the fabric of the original Wright airplane, the clock that Col. Lindbergh used on the Spirit of St. Louis on the flight to Paris, the ribs of the NC-4 and other similar gifts to the Institute he offered to send a piece of the cowling of the famous Southern Cross in which he flew with Sir Charles Kingsford Smith on the first flight across the Pacific Ocean. With this interesting souvenir he also sent a copy of his latest book, "VH-UXX." His other book, "Pacific Flight," was reviewed in the Journal when it was published.

Captain Taylor has a retentive memory, a facile style of writing, and experiences to recount that are not only of great interest but make pages of what will become aeronautical history.

His new book relates his experiences with the late Charles Ulm and others in flying a Fokker type three-engined transport airplane built by A. V. Roe of England and known as an Avro 10, from Australia to England and back in 1934.

The flight established no new record but did add to the interest in the creation of an airline between the two countries The experiences of these pioneers at Jask, Persia, where in intense heat they had to repair their engines, and at Orange, France, where further replacements were necessary, are related in a manner that will show airmen of the future the great difficulties that had to be overcome by the early pathfinders of the air. It was planned to fly around the world but an accident to the landing gear in Ireland prevented its completion and, after repairs were made, the return flight to Australia was made.

The determination of these pilots, in spite of any and all hazards to open new lanes of air traffic, is clearly disclosed in this book. The problems of securing equipment, of operation, and of the difficulties of navigation with primitive instruments and insufficient weather reports are all given with a freedom from self glorification.

The Institute appreciates the gift of the part of the Southern Cross and also the copy of "VH-UXX" for its library.

LESTER D. GARDNER

SUGGESTIONS FOR CONTRIBUTORS TO THE JOURNAL *of the* AERONAUTICAL SCIENCES

The Institute of the Aeronautical Sciences invites both members and non-members from any country to submit papers for publication in the Journal of the Aeronautical Sciences. The Journal, following the practice of other scientific publications, does not pay for contributions.

The following directions for the preparation of papers, if followed by authors, will save correspondence, avoid the return of papers for changes, minimize the work of preparation for the printer, and save the expense due to the charges made for "author's corrections."

MANUSCRIPTS: Papers must be written in English, in original typewriting on one side only of white paper sheets, consecutively numbered, and be double or triple spaced with wide margins. Manuscripts should be prepared with great care so that they will be typographically accurate. Paragraphing should be given special attention. Papers should be written in the third person, reference to the writer being made as "the author." Avoid the use of the words "I," "we," and "you." Blueprint copies of papers are unacceptable as it is impossible to mark directions to the printer on them. Correcting, changing, or adding to papers after they are in type is costly. It is, therefore, imperative that papers submitted be in final form. Typographical errors may be corrected on proofs, but if authors wish to add material, they may do so at their own expense. In mailing, drawings may be rolled, but manuscripts should be sent flat. Send by first class mail (register if you wish for your own protection) to the Secretary, Institute of the Aeronautical Sciences, 5111 RCA Bldg., Rockefeller Center, New York City. All manuscripts will be examined by the Editorial Committee and by the Editor. Authors will be advised as promptly as possible (usually two to three weeks) whether the paper is acceptable for publication.

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SUB-HEADINGS: Sub-headings should be inserted by the author at frequent intervals. The work of editorial preparation will be simplified by the author providing many sub-headings. Owing to the breaking of columns and the insertion of illustrations, some of the sub-headings may have to be omitted.

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REFERENCES AND FOOTNOTES: References should appear as footnotes only, numbered consecutively, grouped together at the end of the manuscript. The arrangement should be as follows; (for books)—[1] Durand, W. F., *Aerodynamic Theory*, Vol. 1, p. 23; Julius Springer, Berlin, 1934. (For magazines)—[1] Englund, C. R., Crawford, A. B., and Mumford, W. W., *Some Results of a Study of Ultra-Short-Wave Transmission Phenomenon*, Proc. I. R. E., Vol. 20, No. 12, pp. 481 and 482, March, 1933. Please give Author, Title, Volume, page, publisher and date of publication as indicated. Omission of one required fact causes much extra editorial work and possible inaccuracies. All references are grouped at the end of the article.

ILLUSTRATIONS: Illustrations should accompany manuscripts and each should always be referred to in the text, preferably by number. Drawings or graphs should not be larger than 12 × 16 inches, and must be made with jet black India Ink on white paper or tracing cloth, the latter being preferred. *Do not use typewriter for lettering.* The smallest lettering on 8 × 10 inch figures should be no less than 1/4 inch high. Cross-section paper (white with black lines) may be used, but should not have more than 4 lines per inch. If finer ruled paper is used, the major division lines should be drawn in with black ink, omitting the finer divisions. In the case of finely ruled paper, only blue-lined paper can be accepted. *Tracing paper and blueprints* are not acceptable. Lettering and all markings must be large enough to be readable after reduction. Mail rolled or flat, never fold. Drawings which cannot be reproduced (including pencil drawings) will be returned to the author for redrawing, thus delaying publication of the paper. Photographs should be very distinct and show clear black and white contrasts. They must be on glossy white paper. Avoid round and oval photographs.

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MATHEMATICAL WORK: Only the very simplest formulae should be typewritten; all others should be very carefully written in pen and ink, the writing to be large enough so that ample room is provided to mark mathematical matter for the printer. A considerable space for marking should be allowed above and below all equations. All complicated equations should be repeated on separate sheets with plenty of space left for marking. The solidus should be used for simple fractions appearing within the text. Make all expressions clear to the typesetter. Greek letters used in formulae should be clearly designated by name on the margin of the manuscript. All symbols should be clearly written and carefully checked. The difference between capital and lower-case letters should be clearly distinguished and care taken to avoid confusion between zero (0) and the letter (o), between the numeral (one) and the letter (ell) and the prime (′), between alpha and a, kappa and k, u and mu, v and nu, n and eta. All subscripts and exponents should be clearly marked and dots and bars over letters or mathematical expressions should be avoided. Avoid complicated exponents and subscripts. When it is necessary to repeat a complicated expression, it should be represented by some convenient symbol.

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INSTITUTE *of the* AERONAUTICAL SCIENCES

AIMS

The Institute of the Aeronautical Sciences is organized to promote the application of science in the development of aircraft. By grading members according to their qualifications, recognition is given to outstanding professional work and an incentive is provided younger members for the investigation of new aeronautical problems. The presentation and discussion of technical papers at Institute meetings afford members opportunities to hear and meet the leaders in the various aeronautical sciences. Through the Journal of the Aeronautical Sciences, members are provided with an opportunity to publish and to read of new knowledge and new applications in the field of aeronautical engineering. By including in its membership the leading aeronautical specialists in other countries an interchange of international thought is made possible. The continuous improvement of aircraft depends on scientific research and engineering experiment applied to design. The Institute desires to bring together all specialists contributing to aeronautical progress and, for this purpose, is keeping the dues nominal in amount, in view of the fact that practically every specialist already belongs to his own special professional society. The dues from members do not provide funds enough both for publication of the Journal and for the Institute's other activities, the difference being made up from funds contributed by benefactors and by the aeronautical industry.

THE SKYPORT, *the headquarters of the Institute, located on the fifty-first floor of the largest office building in the world, provides members when in New York with a convenient and attractive meeting place.*

DUES

The entrance fee for all members is five dollars. The annual dues are: Fellows and Associate Fellows, $10.00; MEMBERS, $10.00; Pilot Members, $10.00; Industrial Members, $10.00; Technical Members, $5.00.

APPLICATION for MEMBERSHIP

Application for membership forms may be secured from any member of the Institute or from the Secretary. An Applicant is required to furnish the names of several members acquainted with his professional work. The Admissions Committee recommends the grade of membership to the Council which, in its discretion, may extend to the Applicant an invitation to join the Institute.

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